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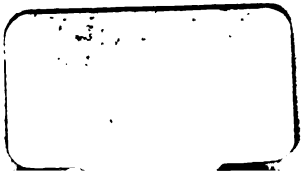

TRANSACTIONS

OF

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IN SCOTLAND

(INCORPORATED).

VOLUME XXIV.

TWENTY-FOURTH SESSION, 1880-81.

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THE INSTITUTION MEDAL,

To Mr JOHN THOMSON, for his Paper on "The St. Petersburg Water Works."

The responsibility of the statements and opinions given in the following Papers and Discussions rests with the individual authors; the Institution, as a body, merely places them on record.

INSTITUTION OF ENGINEERS & SHIPBUILDERS IN SCOTLAND.

(INCORPORATED.)

TWENTY-FOURTH SESSION—1880-81.

Introductory Address. By Mr J. L. K. JAMIESON, President.

Read 2nd November, 1880.

GENTLEMEN,

My first duty this evening is to thank you most cordially for the honour you have conferred upon me in electing me to the office of President of the Institution of Engineers and Shipbuilders in Scotland; but when I recall to mind the names of men deservedly holding foremost places amongst the Civil and Mechanical Engineers and Shipbuilders of our country, who have in previous years occupied the Presidential chair of the Institution, I feel with all sincerity that I must ask the assistance of the Council and Members generally to enable me satisfactorily to discharge the duties of the high position in which, by your kindness, I have been placed; and I trust that our united efforts will prove to be sufficient to preserve the Institution in the advanced place which it has hitherto held, as also to extend its influence in a further degree.

It may be said that we have this evening commenced a new era in our existence as an Institution, inasmuch as we are met, at the beginning of the twenty-fourth session, in what may be designated a house of our own; and we may congratulate ourselves that this event—which has been looked forward to for many years—has been

at last accomplished in a manner worthy of the Institution of Engineers and Shipbuilders in Scotland and the Philosophical Society of Glasgow, the joint proprietors of this very elegant and suitable building.

Before proceeding to describe the arrangements of the building, I shall briefly glance at the history of our Institution.

The Institution of Engineers was founded in the year 1857, and the first President was Professor W. J. Macquorn Rankine, C.E., a man whose published works on Civil and Mechanical Engineering and Shipbuilding are now regarded as "household words" amongst the members of our professions.

About three years afterwards the Scottish Shipbuilders' Association was formed, and the first President of that body was Mr Robert Barclay, wide and favourably known as the founder of the eminent firm of Barclay, Curle, & Co., Shipbuilders and Engineers.

The union of the two bodies just named took place in the year 1865, under the name of "The Institution of Engineers in Scotland, with which is incorporated the Scottish Shipbuilders' Association." The incorporation of the Institution by charter was effected in the year 1871, under the name which it now bears.

Owing to difficulty experienced from time to time in obtaining suitable accommodation for the purposes of the Institution, several propositions were made at various times with the view of building premises on our own account, but none of them were ever carried out. A few years ago, however, our respected Secretary suggested the suitability of the present site, and after much careful consideration arrangements were finally concluded between this Institution and the Philosophical Society—which was similarly situated with ourselves — for a joint ownership. The ground having been purchased, Mr T. L. Watson, I.A., and Mr Millar, C.E., our Secretary, were appointed joint architects. The plans were finally approved by the Joint Building Committee, and the erection of the buildings commenced in the course of last year.

For the benefit of those Members who have not yet inspected the premises in detail I may briefly describe them.

The accommodation consists of Library and Reading Room, on the street or ground floor; on the first floor there is the Hall, or Lecture Theatre, with sitting room for about 300 persons, and the adjoining Council Room; the upper floor is divided into two large rooms for the meetings of the Sections of the Societies, or for other purposes; and on the basement floor we have the Janitor's house, fire-proof safes, store rooms, heating apparatus, lavatories, &c. Every facility is afforded for carrying on the business connected with both societies, and it is expected that the central position of the premises, together with the many advantages to be derived from the Library and Reading Room, will lead to a large increase of the membership.

At present our membership stands thus :—

Honorary Members, ...	7
Ordinary Members, ...	348
Associates, ...	32
Graduates, ...	115
Total, ...	502

During the past year there were added to our membership 19 Ordinary Members and 22 Graduates; in the same period we have lost by death several members, two of them being from our list of Honorary Members, namely Lord Hampton and General Morin.

Lord Hampton, for twenty years President of the Institution of Naval Architects, was best known as Sir John Pakington. At one time the deceased was First Lord of the Admiralty, and subsequently he served his country as Secretary of State for War. When the Institution visited this city in the autumn of 1877, to hold the first of its provincial meetings in the leading centres of shipbuilding industry, the noble lord occupied the Presidential chair; and many persons now present will doubtless remember the kind and genial manners which he displayed on the occasion. General Arthur L. Morin, a distinguished officer of the French army and a mathematician of high rank, was well known by his published works on Experimental Mechanics, as President of the Imperial Commission

for the Exposition Universelle of 1853, and as President of the Society of Civil Engineers in France, to which position he was appointed in the year 1862.

From our list of Ordinary Members we have lost Messrs William Clapperton, James M'Carter, Matthew A. Muir, G. M. Neilson, Hugh Niven, and Lewis Olrick.

Mr Wm. Clapperton was a Member of Council during the Sessions 1874-75 and 1875-76.

Mr Muir, who was one of our original members, was born at Glasgow in the year 1812. In early life he entered the establishment of Messrs Houldsworth & Co., and afterwards spent some time in England, gaining experience in the construction of machinery for spinning and weaving.

His former employers having offered him an important appointment, he returned to Glasgow, and, by his industry and perseverance, gradually advanced to be the managing partner of the firm, which was changed to that of the Anderston Foundry Coy. about the year 1850. He made many improvements in machines and looms, for both cotton and wool, which maintained his firm in the foremost position in Scotland for the construction of that class of machinery.

To Mr Muir the credit is also due of having introduced into the foundry trade the system of plate moulding, by which railway and other castings required in large numbers can be produced with great rapidity and economy. He was a man of a quiet and retiring disposition, but did many kind acts, with unstinted hand, in an unostentatious manner.

Mr Hugh Niven was born at Glasgow, and at his death was in his sixty-eighth year. Having held an important position in the works of the late Mr James R. Napier, and afterwards with the firm of Randolph, Elder, & Co., he was well known in this district.

Mr Lewis Olrick was a native of Denmark, but he resided for many years in London, and was regarded as a man of much sound attainment in engineering science.

Another gentleman belonging to our profession, who has passed

away since the beginning of our last session, deserves special mention here.

I allude to the late Mr James R. Napier, F.R.S., who, though not an active member of the Institution at the time of his decease, was one of its founders, and had occupied the Presidential chair in earlier years. Of the scientific and practical attainments of Mr Napier, as well as of his agreeable intercourse with his professional brethren, I need hardly speak. He held a conspicuous place, and bore an honoured name.

From the Financial Report appended to the Transactions for the Session 1879-80, you will observe that our Institution is at present in a very prosperous condition.

The papers read during last session related to mechanical and civil engineering. Amongst the former class were Mr John Turnbull, Junr.'s paper on Piston Packing; Mr F. J. Rowan's paper on the system of Boiler Construction introduced by his father, the late Mr John M. Rowan; and Mr M'Gregor's paper on Boiler Construction and Efficiency.

Amongst the latter class of papers were those of Mr Day, on the Forth and Tay Bridges; Mr J. Thomson's on the St. Petersburg Water Works; and Mr Imrie Bell's, on the St. Helier's Harbour Works; whilst a paper, descriptive of Experiments on the Strength of Branch Pipes, was read by Mr Thomas Kennedy, and one on Fuel Feeders, by Mr Wm. Clapperton.

These papers, all upon important subjects of considerable interest to engineers, were ably discussed and commented on. The use of higher pressures of steam pointing to changes in form of marine boilers, whilst the consideration of the strength and stability of structures is one of primary importance to civil engineers, especially in this age of gigantic projects for bridging rivers and estuaries.

The placing on record in our Transactions of such facts as those contained in the construction papers on water-supply and harbour works, is of immense importance to a profession which numbers

so many young men studying to fit themselves for carrying on what we must expect to be the still greater works of the future.

In closing this portion of my remarks, I cannot speak too strongly of the desirability of all those members, who have it in their power communicating their views to their fellow members in formal papers, for by that means, principally, shall we be able to maintain the interest of our Proceedings, and eventually the importance of the Institution whose welfare is committed to our keeping. As a rule, we cannot boast of the literary skill which we individually possess—we are generally better acquainted with the handling of materials rather than with the pen of the ready-writer and skilful rhetorician, and have, in most cases, rough and ready ways of explaining our thoughts; but there is no good reason why, through the medium of short, plain, matter-of-fact papers, many of our number should not be both able and willing to add to our knowledge by giving us the results of their experience and thought acquired in the course of their practical work in the workshop, in the mine, in the factory, in the ship-yard, on the ships at sea, on the railway, or otherwise.

In this way our Transactions would become more and more interesting to such of our members as are unable to attend the meetings of the Institution, as also to engineers, and other persons, who receive our volumes in various parts of the kingdom, and in distant countries.

While thus referring to the Transactions of the Institution, I would say a few words about kindred societies, more especially in regard to the method by which some of them improve their usefulness, and add to their membership.

I now refer to the system of occasionally or regularly holding summer or autumn meetings away from the headquarters of the various bodies.

For example, meetings of the Institution of Mechanical Engineers are frequently held in the provinces, and one of these meetings was held in this city last year—a meeting, as you may remember, of great interest and of very marked success.

The Iron and Steel Institute meetings are held alternately in London and some centre of the metallurgical industries in the provinces at home and abroad; and, as already mentioned, the Institution of Naval Architects has shown a disposition to pursue a similar plan.

Some years ago, likewise, a most successful meeting of the Northern Institute of Mining and Mechanical Engineers, of which Newcastle is the headquarters, was held in this city. If scientific and technical societies, hailing from South of the Tweed, find it to be beneficial to hold meetings in Scotland, I think there is abundant reason why we should make an occasional run across the border, and even extend our raid as far as London, or some important centre of mechanical industry where we could hold a meeting.

The propriety of holding such a meeting might, I think, be taken into consideration by your Council.

In noticing a few subjects of special interest at the present time, I would, in the first place, say a few words about great ship canals. The greatest work of the kind referred to, since the completion of the Suez Canal, has been the construction of the canal by which the North Sea and the capital of Holland are brought into direct communication with each other. By this means the distance from the sea to Amsterdam is considerably reduced, and much larger ships can now reach that city than was the case formerly.

The importance of a means of communication suitable for ships, between the Atlantic and Pacific Oceans, somewhere through the narrow neck of land which connects North and South America, has for a long time engaged the attention of eminent engineers and capitalists in both the Old and New Worlds. Surveys had been taken at various points, more especially by French and American engineers, but the difficulty in finding a sufficient amount of capital for carrying out such an undertaking has always proved to be an insurmountable barrier in the way of any definite and feasible plan being proceeded with.

Recently, however, M. Ferdinand de Lesseps, who was so success-

ful in conducting the work of the Suez Canal to a completion, and fitting it for the service of the maritime nations of the earth, has had the Isthmus of Panama surveyed in the neighbourhood of the Panama Railway, and he is now engaged in forming a company for carrying out his scheme.

Situated as this great ship canal would be, about midway between the northern and southern hemispheres, it would afford immense advantages to the commercial interests of the world.

Having myself resided for a period of about ten years in the neighbourhood of Panama, I can confidently affirm that the line selected and surveyed by M. de Lesseps offers many advantages over the schemes of canalization further north and south of the Panama Railway.

The distance from sea to sea, along the line of railway, is 47½ miles, while the height at the summit is only 250 feet above the sea level. There is high land all round the summit level of the railway where water for the use of locks might be obtained, and there are well sheltered harbours at both ends.

Thirty years ago the idea of a railway across the Isthmus was deemed a visionary scheme, but after years of toil and perseverance the extraordinary work was accomplished, and speedily became a great success commercially.

The existence of the railway near to the line of the proposed canal will materially contribute to lessen the difficulties connected with this great undertaking.

Let us hope that M. de Lesseps may be successful in accomplishing the work, for which he has extraordinary abilities and energies. There is scarcely room to fear that as the period of commercial depression draws to a close, and the capitalists on both sides of the Atlantic regain their usual confidence, the great enterprise will be commenced and prosecuted to a successful issue.

To the great bulk of the Members of this Institution the subject of steam navigation, in the widest acceptance of the term, is one of perennial and professional interest, inasmuch as the major proportion

of them are in some way involved in the construction of ships and in their subsequent management.

At the present stage in the history of the subject, therefore, a brief retrospect and reflection may not be out of place. Those amongst us who are old enough to look back over a period of forty years, and review the progress and development of the steam shipping of the United Kingdom during that time, cannot but be struck with the thought that suggests the question—If we have made such advances in the past, what are we likely to do in the future, say twenty years hence? I think that a very safe conclusion to come to, is, that we cannot tell. Calculation can make no progress in a question such as the one just suggested, and the imagination is left to draw the picture.

We are certainly living in an age of rapid and most wonderful progress. Shortly before the period mentioned, the well known scientific professor and author, Dr Lardner, had stated that it was highly improbable that a steam ship should be able to make the voyage to America commercially possible under steam alone. The prediction of the philosopher, however, was fated to be soon widely contradicted, and to be demonstrated by actual practice to have no sound scientific basis. If not already settled by the steamers "Sirius" in 1838, and by the "Great Western" in the following year, the possibility of steaming across the Atlantic to a United States seaport was abundantly demonstrated in the year 1840 by the "Britannia"—which was the pioneer of the Cunard fleet—commencing the service between Liverpool and Boston and performing the voyage from port to port in 14 days and 8 hours; her sister ships did equally good work. Though magnificent vessels in their day, now forty years ago, they were not large as ships go now, the first four being under 1200 tons. Ever since then we have been increasing the dimensions of our ships and lessening the time between the old world and the new. Then the voyage of the fastest steamers required between 14 and 15 days, now it is accomplished by some vessels within 7½ days. Up to this time the S.S. "Arizona" has made the most rapid passages, her time being from Queenstown to

Sandy Hook 7 days 10 hours 49 minutes, and from Sandy Hook to Queenstown 7 days 8 hours 9 minutes.

Surely it is not too much to expect that in a few years hence it will be accomplished in six days, and that we shall have steam ships starting from each side of the Atlantic every morning, noon, and night, and arriving in the ports on the opposite shores with as much regularity as our present express railway trains are due at the termination of a journey of 400 or 500 miles.

The time occupied by steam ships on the voyage between Great Britain and Australia has also been much reduced recently. Several passages have been made from Plymouth to Adelaide *via* the Cape of Good Hope, within 36 days' steaming time, and one ship has done the same voyage in 34 days 2 hours. We may, therefore, consider the day near at hand when a voyage from this country to Australia may be accomplished within a month.

On the question of the rapid increase in the size of ships, I may refer you to some interesting remarks made by a distinguished predecessor in this chair. Mr Robert Duncan, in his opening address in October, 1872, said, when he designed some new ship-building works a few years previously, he arranged for the construction and equipment of steam ships 500 feet in length, and thought he was providing for a considerable future. Unless the "Great Eastern," few vessels of over 400 feet long were then afloat; now we have several working close on 500 feet over all; others building, or about to be built, approximating 600 feet. At that time I also find him saying: "Coming events do not cast very long shadows now-a-days, and looking forward one generation, and measuring the future by the past, I think it is not problematical that we shall see steamers of 800 feet long the ferry-boats of two oceans, with America for their central station, and Europe and Asia for their working termini." Such remarks show Mr Duncan to have more of the gift of prophecy than the philosopher of forty-two years ago.

To a great extent there is at present a limit to the size of ships, on account of the limits of the rivers, harbours, and docks they have to frequent; on the other hand, there is practically no limitation to

the power of the engineer and shipbuilder to produce vessels of dimensions never reached hitherto, and it is within the bounds of possibility that by some alteration in the relationship of the dimensions to each other, naval constructors may be able to obtain increased carrying powers, and thereby confer advantages on the maritime commerce of the world.

Whatever results may be arrived at in the early future by the leaders of engineering and shipbuilding progress, there is no doubt that great achievements in construction, which were only recently regarded as possibilities or probabilities, are now among the actualities.

Glancing at another phase of the subject of steam navigation—namely, that of the power employed to drive the vessels—we cannot remain uninterested in the change which is taking place, ever since the introduction of the compound engine for marine purposes, in the way of bringing increased steam pressures to bear upon the driving machinery.

Without speaking of the high steam pressures used on the "Thetis" and "Propontis," as treated on in Mr Fred. J. Rowan's paper before referred to, or the much higher pressures employed in accordance with the "Perkins'" system, we have the very patent fact that steam pressures have increased with rapidity in the ordinary commercial marine. A pressure of 90 to 100 lbs. per sq. in is not now deemed extraordinary, whereas few if any of the vessels belonging to our large steam ship companies fitted with compound engines were working with a higher pressure than 60 lbs. six years ago.

This increase in the pressure of steam, coupled with higher piston speed, and the use of steel in many parts of boilers and engines, has enabled more power to be obtained from an equal amount of material used in the construction of machinery, than we had a few years since.

Engines developing 6000 I.H.P. driving a single screw are now working in a steam ship employed in the Atlantic trade, and ships are now building for the same trade that will have engines placed on board of them capable of working from 8000 to 10,000 I.H.P.

I need scarcely remind you that this very rapid development of size, power, and speed in our ocean steam ships is mainly due to the reduction in recent years of the fuel required to drive them, and that this reduction in consumption of fuel is owing to the employment of the compound engine.

Shipowners, engineers, and shipbuilders have all contributed to bring about the development I have sketched, but it is scarcely possible to separate the part done by one from that done by the other; it may, however, be truly said that their united efforts has done much towards advancing the welfare of the human race.

Up till about the year 1840, the material of which ships were built was almost exclusively wood. Now, however, wood, as the material of construction for the hulls of ocean-going ships, has practically, if not absolutely, gone out of use in Great Britain. Iron has taken its place, and within the last few years a comparatively new material has come into use—namely, ingot iron, or mild steel, by both of which names it is known. Judging by the recent progress in the adoption of that material for constructing the hulls of ships, and various portions of their machinery, we need have no hesitation in predicting that, as certainly as iron displaced wood, so certainly will iron itself be displaced by mild steel.

The superior material is bound to supersede the inferior, so soon as it can be produced at a moderate cost. With the introduction of a lively competition among the makers of mild steel, it may naturally be anticipated that a less costly material, not inferior in quality, will soon be made. In our own neighbourhood we have had for some years extensive works, specially designed for the production of steel, where great attention has been given to the manufacture of mild steel for engineering and shipbuilding purposes, and several of the large makers of malleable iron in the County of Lanark have erected, while others are erecting, additions to their works for turning out this material. One of the establishments referred to has already supplied nearly 150,000 tons for shipbuilding purposes, and about 10,000 tons for making land and marine boilers.

It is a fortunate circumstance that, at the time ships are rapidly

increasing in dimensions, and the machinery required to drive them becoming of greater power, a superior material is placed at the disposition of shipbuilders and engineers, which enables them to deal more confidently with the work they have to design and construct.

Mr DAVID ROWAN had very great pleasure in proposing a vote of thanks to the President for his very excellent address. The President had wisely allowed himself to be guided in his anticipations of the future, regarding the dimensions and speed of steam ships, by the experience of the past; and certainly such experience naturally led us to anticipate more marvellous results in the future than we have yet seen. When we think of the time, considerably less than half a century, since the first steamer crossed the Atlantic to America, and more especially since the first iron screw steamer was built on the Clyde—the "Fire Queen"—by Robert Napier, in 1845, only thirty-five years ago, and the present time, when every sea is traversed by iron-built screw steamers of various dimensions, and that at speeds that could not have been contemplated a few years ago, they must confess that the President was not too extravagant in his anticipations for the future as indicated by the experience of the past. He had no doubt that the anticipations given might reasonably be expected to be realised before many years passed over. They had all the appliances and experience necessary to build vessels of any magnitude, of any power required, and of a speed attainable within reasonable limits. There is one limit which must be attended to—they must not build vessels that will not pay. The anticipations from new material had been wisely stated as of great importance in giving them advantages over the past; and yet it was a singular thing that at the present moment there were still some people sceptical of the use of that famous material, steel, in the construction of steam boilers. However that might be, he was able to state emphatically that so far as his experience he had never had a bad plate nor a complaint of any boiler made of steel. He had no doubt whatever that they were approaching the time when no other material would be used in the processes of shipbuilding and boiler-

making. He had also to congratulate the Institution on this the first meeting in their new building. He thought the accommodation was most admirable and well adapted for the purposes intended He had been afraid that the lecture-room would be too confined; but he was glad to see, from the skill of the architect, that the accommodation was ample, and that it was well calculated to see and hear in. He did not think they could have a better building, or lecture-room, although they had to devise it over again. They had every reason to be pleased with it; and he congratulated the President; and begged to move a hearty vote of thanks to him for his address.

The vote was heartily accorded.

On the Application of Hydraulic Pressure to Machine Tools.

By Mr RALPH HART TWEDDELL.

(SEE PLATES I., II., AND III.)

Received 1st November; Read 2nd November, 1880.

The author purposes to confine his remarks to the application of hydraulic pressure to machines used for constructive purposes.

It is not necessary, so far as the historical portion of our subject is concerned, to go back very many years, and yet there is not an entire absence of history connected with hydraulic engineering, for we read that 200 years B.C. one Ctesibius, the teacher of the better known philosopher Hero of Alexandria, discovered and applied the principle of the air vessel to pumps. Hero describes an apparatus worked by water to open and shut the doors of a temple, but hydraulic machinery first became an important branch of engineering with the inventions of Joseph Bramah towards the close of the last century.

Mechanical skill, or even the inventive faculty itself, are not, however, alone sufficient to successfully introduce and bring into practical use a new system, and it was not until 1836 that Sir William Armstrong took up this subject and made it a success. Thus while the credit due to Bramah for his hydraulic press is not at all diminished by the fact that a French philosopher, Pascal, propounded the theory 150 years previously, on the other hand, much is due to the late Benjamin Hick for his invention of the cup

leather, which really enabled the press to be *practically* worked. No historical notice of high pressure hydraulic machinery would be complete without reference to what is now generally termed the accumulator. In 1810, Matthew Murray, of Leeds, supplied water to a direct-acting hydraulic hoist for lifting boilers from a tank or reservoir 60 feet high; this seems one of the earliest *artificial* reservoirs so employed.

In 1847, the late Sir Charles Fox patented an accumulator, which he describes as follows:—

"The presses which I construct for these purposes (forging, &c.) are furnished with separate reservoirs of a cylindrical or other convenient form, containing water compressed and loaded with weights to the required extent, and are so constructed that the water contained in such reservoirs may be speedily forced into the ordinary cylinders of the presses and the water speedily ejected from such cylinders, in order that presses may thus be made to operate more expeditiously for the purposes of producing the required effects."

Mr E. A. Cowper informs the author that this was made by Fox, Henderson, & Co., in 1847, and that they worked at first with a pressure of two tons per square inch, finally reducing this as it was found more than was necessary; the idea, however, he says, was taken by him from noticing during a visit to some paper mills in London that, to save the trouble of charging independently each of the hydraulic presses employed for pressing paper, the men connected all the presses with one loaded press, and this being kept constantly supplied by the pumps was always ready to run up the others.

In 1849 or 1850, Sir Wm. Armstrong, finding that in one instance there was no possibility of obtaining pressure by a natural head of water, and the alternative of an air vessel not having proved very satisfactory, he was, in his own words, led to the idea of a new substitute for an elevated reservoir; this consisted of a large cast-iron cylinder fitted with a loaded plunger to give pressure to the water injected by the engine; this contrivance he called an "Accumulator," and it is now generally known by that name.

In 1851, Mr Michael Scott patented what he termed a steam

accumulator, in which the load is obtained by steam at a low pressure on a large piston connected to a smaller plunger in the accumulator cylinder, but, except under very peculiar circumstances, this is an expensive arrangement, and the results differ but little from those obtained by using a large pump.

Eliminating Bramah's press, patented in 1796, any retrospect of hydraulic pressure as applied to *machine tools* need go no further back than the year 1846.

In 1845, Garforth casually mentions in patenting a steam rivetting machine (formerly much used), that it could be worked by steam, air, or water, but it does not appear that it ever went further than the paragraph in question.

Sir William Armstrong, many years later, converted a steam machine and substituted water as the motive power.

In 1846, Mr Charles May patented what may be considered the earliest proposal to use Bramah's press as a punching or rivetting tool. This machine, if it was ever made or tried, never came into actual use. The idea of using water does not seem to have even then been new, as he mentions that it has been previously proposed to use it for this purpose; his machine assumed the shape of a horse shoe. Once let the idea occur to any one that a Bramah press may as easily be used to compress a rivet as a bale of cotton, and it only remains to adapt this hydraulic power to the existing frame or jaws of an ordinary punching machine and use it for rivetting.

In 1847, Fox applied the Bramah press to forging; by its means a great deal of welding was done, and most of the later improvements in this branch have been in the details. Sir Charles Fox, however, proved that satisfactory welding could be done without the blow of a steam hammer.

It may here be mentioned that in 1861, Haswell of Vienna patented a special form of press and pump for forging cranks, &c., and has done very remarkable work in this way. This class of hydraulic machine tools would, however, require a paper to itself All later applications to forging and welding by hydraulic pressure

have necessarily followed in these grooves. It is very much a question of moulds and dies and the power of the press.

Closely allied to this subject is Sir Joseph Whitworth's compressing apparatus (another process quite impracticable but for the genius of Bramah). The general use of hydraulic pressure for forging and stamping has up to the present been retarded owing to the absence of sufficient hydraulic power in works. This difficulty is, however, gradually disappearing, and in the author's recent practice he finds a greater disposition among engineering firms to put down large accumulator and pump power at first with a view to avail themselves of further applications of this power.

In 1853, John Bourne patented not only a portable rivetting machine, but showed how it might be applied; but it does not appear that he ever did apply it—it certainly did not come into use. The rivetting machine was similar to May's already described.

In 1864, the author designed a hydraulic machine tool for fixing boiler tubes in their tube plates. Many thousand tubes were satisfactorily secured by these machines. Its success, however, depended too much on the accurate boring of the holes in the tube plates, and also upon the truth of the tubes themselves.

By means of a very strong india-rubber hose pipe, high pressure water was forced into a cylinder pushing out a piston, and by drawing the tapered wedge outwards the dies expanded and compressed the tube into its seating. The wedge motion itself was old, but had in the hand machines been driven inwards by a hammer. The india-rubber hose was, however, found troublesome and unreliable, and copper hose was substituted, enabling at once a pressure of $1\frac{1}{2}$ tons per square inch to be used, and the size of the machine proportionately reduced. Sixty tube ends have been done by this tool in one hour.

These results were sufficiently encouraging to induce the author to proceed further, and as at that time high pressures of steam were becoming common and, owing to the large diameters of boiler shells, very thick plates had to be used, much difficulty was experienced in

getting the rivetted joints tight. In 1865, he designed a stationary hydraulic rivetter, and Messrs Thompson, Boyd, & Co., of Newcastle, made one for their own use. The excellence of the work done and its economy becoming known, the above firm for several years manufactured these machines for sale, and in a comparatively short time above 100 machines were at work in the principal Government dock yards and large works in the kingdom and abroad. This is perhaps the best moment to explain this system of rivetting.

In observing the work done by steam rivetters, it was evident that an increased area of piston did not produce proportionately better work, while it vastly increased the first cost of the machine and foundations, and also the working expenses, owing to the extra quantity of steam used. This being so, it occurred to the author that if merely increasing the percussive force did so little good, whether the addition of the same steady pressure or squeeze, so efficient in his previous machine, would not hold the plates, as it were, in a vice, while the rivet was being forced into all the crevices and headed. This proved to be correct, but as there was much in favour of giving a sharp blow also, this was effectually obtained in combination with the steady pressure or squeeze by the use of an impact accumulator. The effective area of this accumulator is much smaller than that of the rivetter ram, consequently it falls through a greater height than the travel of the cupping die. This causes a momentary increase of pressure amounting often from 30 per cent. to 40 per cent. above the static pressure, which nips the plates close together, while they are prevented from springing apart again by the steady pressure from the ram, which can be maintained as long as desired.

This general combination of a rivetting machine, force pumps, and accumulator—this last acting not only as a reservoir of supply water, but of a percussive force also—formed, so far as the author is aware, the first hydraulic rivetting plant brought into practical use and capable of doing work economically.

In 1866, Mr Bunning patented a portable rivetter. The successful action of this depended upon getting a tension rod of sufficient

strength to withstand the pressure on the cupping die. It did not come into use, for reasons which need not be here gone into

Messrs M'Kay and M'George patented a hydraulic rivetting machine in 1871, the levers working on a fulcrum like a pair of scissors.

Five years previously the author had designed a portable rivetter, but it possessed the objections of previous designs, namely, that the cylinder took up too much room. To remedy this defect, it occurred to him to transmit the power through the intervention of levers, and in 1871 he patented and in 1872 worked the machine shown on Fig. 3. In order to utilise the levers as much as possible he adopted a lever of the third order, placing the cylinder A between the fulcrum B and the rivetting dies C. By making the levers of different lengths, the pressure at either end proportionately differed, and by interchanging the dies, either side could be used for rivetting; the machine was thus a double-powered one, closing large rivets at the shorter gap D and small rivets at the longer gap E. The machine was also extremely well balanced, and the tension rods were so arranged that the distance between the levers could readily be altered.

The enormous quantity of rivetting in connection with iron ships had also attracted the author's attention at this date, and it will be seen by Fig. 4 that so far back as 1871 the subject had been gone closely into. The diagram shows portable machines as applied to rivetting up keels, floors, frames, &c.

But although in 1872 frames were being rivetted by the hydraulic fixed machines, it was not until later that Messrs Fielding & Platt, of Gloucester, who had undertaken to make the machines, used a portable rivetter on ships' frames, putting in 1000 rivets per day of 10 hours with one machine. Not much encouragement was, however, received from shipbuilders, although a modified mode of working, was proposed by the author in 1876.

This plan was generally approved of by many of the principal shipbuilders on the Clyde, to whom the author showed his plans, some five or six years ago.

The first cost, however, and the fact that rivetting labour was not

then a very urgent question, made the moment inopportune for its introduction. The author, however, has the satisfaction of knowing that the general plan of working proposed by him in 1876 was very generally adopted shortly after.

This mode of working is extremely simple, and supposing proper tackle to be put up, will not be improved upon until shipbuilders put "travellers" over each vessel. But it may be mentioned that, if shipbuilders are supplied with suitable rivetting machines, their application to their work can generally be, to a great extent, left in their hands. The conditions of working vary not only on every river, but in every shipyard, and to the assistance and hearty co-operation of shipbuilders in this respect, much of the success so far achieved is due.

In Fig. 5, two cranes, A A, are placed at either side of the head of the berth, the frames to be rivetted being laid across the end of the keel. These cranes have sufficient radius to command the whole area of the cross section of the ship, as represented by a frame. As soon as the frame is rivetted, it is drawn along the keel and upended. These cranes can either be fixed on posts at the end of each berth or made moveable on a trolly, as in Fig. 6. The advantage of this latter arrangement being that they are easily moved from berth to berth or along the floors of the vessel when doing intercostal work. Much difference of opinion has arisen as to the advisability of reducing the working pressure sufficiently low to enable flexible india-rubber hose to be used, but it is not suitable for bridge and shipyards, where sharp corners, hot rivets, &c., are to be guarded against. The slovenly appearance also of these pipes, generally served at intervals with bandages, is objectionable.

It may be of interest to mention, that when the author first supplied his hydraulic rivetters to Sir Wm. Armstrong's firm, 1,500 lbs. pressure per square inch was adopted, although their own pressure of 750 lbs. is laid all over their works. The fact is that the higher pressure of 1,500 lbs. per square inch has as many advantages, when used for machine tools, as it has disadvantages for dock and warehouse machinery, as introduced by the Elswick firm.

Fig. 6 shows the principle of the transmission of pressure by walking pipes as fitted to a travelling crane. Between a stop valve, A, on the main and a swivel joint, C, at the foot of the crane posts, two walking pipes, B B, are placed; these allow the crane to travel along rails on the ground. C is connected by a pipe, D, to a swivel, E, at the foot of the crane post, thence a pipe, P, conveys the pressure to Q, walking pipes, K, conducting the water thence to a hydraulic lift, G, on the carriage, F.

This lift is arranged to serve also as a passage for the pressure water. A copper pipe, H, conveys the pressure from the lift to the rivetter.

In more recent practice this pipe, H, is dispensed with by means of a special hanger arranged to act as a supply pipe also. Thus it will be seen that no pipes, in the usual sense of the word, are required, while at the same time the rivetter is free to move in any direction.

The valve for working the lift being placed on the end of its piston rod, forms practically part of the rivetter itself without the necessity of having to place a lift valve on each machine. Similar machines have put in from 1,800 to 2,000 rivets each per day at the works of Messrs P. & W. Maclellan of this city.

In considering the question of rivetting machinery in connection with shipyard work, we have given this class of work undue precedence in point of time, for before either ship rivetting or waggon work were successfully accomplished, the author's portable rivetters had come into very general use for bridge and girder work. In 1873, Mr W. H. Panton, the contractor for the erection of the Primrose Street bridge on the Great Eastern Railway at London, employed on this a travelling carriage similar to that shown in Fig. 7, for rivetting up this structure *in situ*. Temporary rails being laid along the platform of the bridge, the whole rivetting apparatus followed up the work as it was plated.

This bridge was of a similar type to the new Caledonian Railway bridge in this city, which was erected some six or seven years later, and also rivetted up by hydraulic pressure.

The flanges were rivetted up by a machine similar to that shown in Fig. 3. The vertical plates, which were from 2 feet 6 inches to 2 feet 9 inches deep, were rivetted up by another class of machine, B. In this case the cylinder did not come in the way, as it could always be kept outside. When, however, there are three or more vertical plates, either a large machine of the type shown (Fig. 3) could be used, or a machine similar to that shown (Fig. 10), to be hereafter described.

Fig. 8 shows at 1 a hydraulic rivetter, patented by Mr Arrol of this city in 1877. This consists of two standards connected together by flat bars. It will be seen that this machine only differs from the one used on the Primrose Street Bridge in 1873, and shown at B, Fig. 7, in flat bars being used, instead of adjustable screws bolts, to connect the standards. Another machine patented at the same time overcame the objection, common to the above tools, of the cylinders being in the way; this was effected by using an arrangement of levers of the same order as those shown in Fig. 1 (M'Kay & M'George's machine); but Mr Arrol prefers to use two centres instead of one. In other respects the machines are similar, and the pressure used in both cases is about 800 to 1000 lbs.

Before leaving the subject of ship rivetting, two special machines should be referred to. Owing to the small depths of the rivet heads in keel work, the size of the rivets, and other causes, in order to rivet those well and soundly, a special form of machine (Fig. 9) has been found necessary. Revolving on the trolly, A, is a short post, B, supporting a turntable; on this table a pair of levers, C, attached to a carriage, D, are free to traverse in and out; these levers carry the rivetter, E, which is free to rise and fall to suit the varying heights of the keel and the seams of rivets. The weight of the rivetter itself, which is very powerful, is counterbalanced by a balance weight, W; a parallel motion, G, is provided to keep the machine vertical, while a further more minute adjustment is obtained by a small eccentric at K. The keels of the "City of Rome," "Servia," and other large vessels, have been and are being rivetted up by these machines. It will be observed that the rivetter, although

of the bear type, has a flush-topped cylinder at H; this enables the machine to get at the rivets, even when the bilge is quite flat, and yet retain a direct-acting pressure.

Too much stress cannot be laid upon giving *ample pressure* on all machines for rivetted work; if this is neglected, nothing is easier than to get light machines, but it is not only necessary to make a head to a rivet, what should be insisted upon is, that the plates be *well and closely laid*, and the quality of ship rivetting made equal to boiler or the very best girder work.

Fig. 2 shows a similar flush top principle, adapted to a fixed rivetting machine. It will be seen that, while a direct pressure is obtained, such work as the rivetting in the throat of locomotive boilers, flanged joints, or furnace tubes, can be reached.

It is illustrated as showing the improvements effected in the ten years since Messrs Elder, Caird, and others on this river, first adopted the author's system.

Many designs have been brought out within the last few years, their object being by the use of toggle joints, &c., to economise the quantity of water or steam used. Some early steam machines have had all this gear removed and direct-acting hydraulic cylinders put in their place, and when all the objections to such gearing are considered the extra quantity of steam or water used in direct-acting tools is far more than compensated for by the certainty of obtaining the same pressure on the rivet head under all circumstances. The samples exhibited, one showing 24 plates each $\frac{1}{2}''$ thick, and another representing a section of the keel of S.S. "Servia," show, that by using a sufficiently high initial pressure per sq. inch of water and suitable designs, no such gearing as toggle joints is required to obtain the required pressure, or to reach the difficult parts of rivetting work.

A diagram is also exhibited showing how, if necessary, every rivet in a marine boiler can be closed by the use of fixed and portable hydraulic rivetters.

The last rivetting machine to be noticed is that shown in Fig. 10, which shows a machine having a similar order of levers to that shown in Fig. 1, into which, however, an important structural improvement

is introduced. This consists in the central axis of the ram and cylinder forming a portion of the circumference of a circle whose radius is the distance from the fulcrum, A, to the central line of cylinder, B. By this modification Mr John Fielding avoids all connecting rods and toggles between the levers, and renders the machine equally stiff, so far as all side strains are concerned, as if it were all one casting; at the same time, it leaves the rivetting dies clear. The author takes this opportunity of acknowledging the valuable assistance he has received from his co-patentees, Mr James Platt and Mr John Fielding, in the designing of many of the more recent types of machines on his system, so far as they are applied to rivetting purposes.

The consideration of hydraulic pressure for rivetting has left little time this evening to devote to other hydraulic machine tools. It must not be supposed, however, that there is not quite as important a field for other applications; but in the case of the substitution of hydraulic tools for punching and shearing in the place of existing geared machines, we have to replace machines already capable of doing, so far as power is concerned, the general run of work. Nor can there be any difference in the quality of the holes punched and plates sheared, so far as the hole or the cut is concerned, which in both cases will depend upon the condition of the punches, dies, and knives. Consequently there does not exist the same margin for improvement as when replacing hand rivetting, so far as regards the *quality* of the work is concerned.

But a little consideration will show that (*1st*) greater accuracy can be obtained by hydraulic machines, because of the perfect control of all the movements; (*2nd*), that greater economy in cost of working can be obtained; (*3rd*), that the entire absence of gearing removes all necessity for shafting and overhead structures; and (*4th*), that the heavier the work to be done, the more economical the results obtained.

We have already alluded to the question of hydraulic forging, and in the operations connected with flanging we have a very promising field for the use of hydraulic pressure.

In 1866 and 1867 the author had made several hydraulic presses for joggling and bending angle irons, some of which were also used for stamping Mallet's buckled plates, flanging plates, &c. The success of these last gave hopes for the future extension of hydraulic flanging. In 1870 and 1872 Gustav Piedbœuf, of Aix-la-Chapelle, patented a flanging press, the valuable and novel feature consisting in the use of auxiliary cylinders, the rams in which acted as a vice, and prevented any buckling. In 1874, Messrs Fielding & Platt designed and made a hydraulic press (see Fig. 11), which enables all parts of locomotive and other boilers to be done very quickly, and with great accuracy.

In Fig. 11, H and B are top and bottom castings, C is the moving table or follower; on this bottom casting, B, is fitted a matrix, D, of any desired shape. The plate to be flanged being placed on the top of the matrices, D, when the block, E, descends, the plate is turned over upon its edges. To prevent any buckling, provision was made in the casting to receive, at a future time if found necessary, another cylinder, G, carrying on its ram a table, H; pressure being admitted to this lower cylinder, the plate can be tightly held as in a vice, between the blocks, E, and table, H, and no buckling can take place during the further descent of block, E. Although in this case the auxiliary cylinder was not applied, Piedbœuf had used the same device, in a slightly different form, both here and abroad, for some years.

Flanging by hydraulic machinery has now become very usual, and although a good machine is expensive at first, few machines are a better investment, if there is work enough for them.

In 1872, the leading test works in England adopted hydraulic shears for cutting chain cables, as designed by the author. Some of these worked direct from force pumps, others from an accumulator loaded to 2000 lbs. per square inch. They proved very efficient and economical, in repairs; but in order to enable hydraulic machines of this class to compete with geared machines in speed and economy, it is necessary so to design them so that at least from 15 to 20 strokes per minute can be made, and also that, by some simple means, the

consumption of water may be proportionate to the different thicknesses of plates to be punched. Hydraulic machines for punching and shearing, however, are now made in which the speed of working is equal to that of any geared machine. One of the earliest of these, equal to punching 1¼-inch holes in 1¼-inch plates, at 5 feet from the edge of the plate, was fitted with a tappet motion to regulate the consumption of water in accordance with the thicknesses of plates.

Hydraulic machine tools have an unique and valuable property—namely, that there is absolutely no loss of power going on when they are not actually performing work. When geared machines are used, on the contrary, we have, during the same period, to supply power to drive all the works' shafting and belting, and as a rule, also the gearing on the machine itself. A great part of this power is exerted to drive machines running light; with hydraulic tools this is not so, and this is found to far more than compensate for the loss arising from the non-expansibility of water. As is well known, this compels us to use the same quantity of water, whatever be the power required; and as this water has all been subjected in the accumulator to the maximum pressure, it is apparently a defect in theory, but in practice it is not so.

In dealing with the machine tools now in question, however, the strokes are very short, and the actual loss from the above cause is still further reduced by the tappet motion. A vertical rod is connected to the valve lever, and on this rod are two adjustable tappets. An eye on the outer end of a spur, fixed to the ram of the machine, embraces the vertical rod, and travels between the two tappets. Should the ram be descending upon the spur, catching the lower tappet, it draws down the valve lever, and opens the valve to exhaust; and in ascending it catches the upper tappet, and closes the valve to exhaust. It is obvious, that if a stroke of even 1¼ inch is required for punching an inch plate, a stroke of say ⅝-inch to ¾-inch would do for a ½-inch plate; and this smaller stroke is obtained in a moment by screwing down the upper tappet.

Many structural advantages are obtained by the employment of hydraulic power for these tools. Each cylinder, and therefore each

tool-holder, is independent of the other, consequently a break down in the one does not cripple the whole machine. A stroke can be made by each without waiting for the other, so that the men working at either end are quite independent. If desired, the machine can be subdivided and placed in different parts of the shop, or can be worked upon the deck of a ship lying in an adjoining graving dock or at a quay, by simply leading pipes on board.

The last machine tool which will be referred to is an angle iron or beam straightener and bender. In Fig. 12, a similar tappet gear to that already described in connection with the punch and shears is used, and a right and left handed screw carries the abutting blocks. By these improvements any number of curves can be made identically the same, the travel of the single block being regulated by the tappet gear and the position of the double blocks by the right and left screws, which can also be disconnected if desired.

In common with all hydraulic machine tools worked from an accumulator, if they are made strong enough in the first instance, there is no liability to fracture, should work beyond their powers be given them to do. This is due to the fact that the load due to the accumulator cannot be exceeded, and the machine simply pulls up.

Experience has taught us that the momentum of a fly wheel acting through gearing frequently produces in such cases most disastrous results, since in practice it is not possible or usual to make the gearing strong enough to withstand this exceptional strain.

In 1875 a large shop was entirely fitted up with hydraulic punching, shearing, and bending machines from the author's designs by the Hydraulic Engineering Company (Limited), of Chester.

In the French Arsenal at Toulon the new plate and angle iron shop is 377 feet long and 164 feet wide. The following hydraulic machines were supplied amongst others:—Two powerful quadruple punching and shearing machines for steel angles up to $6\frac{1}{4}'' \times 6\frac{1}{4}'' \times \frac{5}{8}''$, and several angle benders and straighteners of similar type to Fig. 12, some of these exerting 100 tons pressure. These last are for working the heavy steel channel irons and in the construction of armour clads. There are numerous hydraulic cranes, and also a stationary

rivetting machine having 6½ feet gap and exerting 40 tons pressure. A number of portable rivetting machines were added later on and used for rivetting up the cellular bottoms and decks of the ships. These last work at a distance of some 1,300 feet from the accumulator, and altogether the total length over which the pressure mains are laid in order to reach wharf cranes, &c., is about 2,500 feet. The pumping station cons sts of very powerful engines and accumulators. Owing to the economical results having, however, exceeded anticipations, in future cases less engine power would be put down. The pressure used is 1,500 lbs. per square inch, and the pressure and return mains are laid side by side under the floor. The entire absence of shafting or gearing on the machines enables the work to be done in perfect silence.

Overhead cranes here meet with no obstacles, the saving in machine foundations is considerable, and the walls and roofs only being required as a protection from the weather, no provision to enable them to support shafting is required, and thus another great reduction in outlay is effected. The author regrets that the time at his disposal this evening prevents a further consideration of this the latest development and most complete application of hydraulic power to machine tools; but he cannot conclude this brief allusion to the Toulon works without owning his indebtedness to his colleague in the work—Mr Henry Chapman, C.E. of Paris—by whose aid all prejudices and objections to so novel an installation were successfully overcome.

The results in actual working will be found in a paper read at Paris by a distinguished French engineer, Mons. Marc Berrier Fontaine, before the Institution of Mechanical Engineers in 1878. Briefly, the result of this bold departure on his part from previous practice is this, that a very much smaller prime mover is required. A moment's consideration will show that when gearing is used the prime mover must be equal to the maximum demand, which can be made on it at any one moment. The accumulator, however, affords a smaller engine the opportunity, when not otherwise fully engaged, of storing up by easy stages an amount of power equal to the greatest

demand likely to be made, and as long as the work required is not equal to the power of the pumps, this process of putting by power, as it were, is going on, consequently a much smaller prime mover will suffice, which means less boiler power and a more economical use of the steam.

In such cases as shipyards it is not too much to say that the same quantity of work can be turned out with from $\frac{1}{3}$ to $\frac{1}{4}$th of the motive power now required.

An objection frequently raised to the use of hydraulic power is the trouble likely to arise from very severe frost.

The author's ideas on this subject are that in this country, at all events, there need be no difficulty apprehended so far as machines under cover are concerned, if proper precautions are taken, and that when the frost is too severe to allow the machines to be worked in the open, the workmen cannot work to much advantage either.

The introduction of hydraulic machine tools for punching and shearing will for some time be gradual, owing to the large sums already invested in geared machines, which it would be mere affectation on the author's part to assert are sufficiently inefficient to justify immediate condemnation; but it cannot be doubted that the first engineering or shipbuilding firm, who, in commencing new or extending their present works, try the hydraulic system will find that besides being accompanied by less noise and requiring fewer men, the work will be done quicker, better, and cheaper.

While the author has endeavoured to give a brief history of the various machines having reference to the application of hydraulic pressure to machine tools, he cannot conclude so far as his personal share in this branch of engineering is concerned, without acknowledging the valuable assistance and suggestions received from those engineers with whom he has had the pleasure to be associated, both in the introduction and the carrying out of his system.

The PRESIDENT said that the paper read was a most interesting one. Every one connected with works where hydraulic machines

were used knew the great benefits they conferred, and that they were coming more and more into operation, and every year becoming more appreciated. Personally he had no hesitation in saying that they would see them very largely introduced into all new works. Mr Tweddell had truly said that people were unwilling to throw away good machinery to make room for hydraulic machines; and therefore he thought they must look for their introduction chiefly into new works.

Mr D. ROWAN remarked that the subject of hydraulic rivetting, and the various modes of applying machines for rivetting, had been clearly put before them. It was not to be supposed that they were entire strangers to the subject; but at that late hour he thought it would be better to defer the discussion of the paper till the next meeting, after they had it printed and distributed among the members. He thought the subject was so important in itself that it should not be taken up that night, but rather after they had thought over the subject, with the paper before them.

Mr JAMES M. GALE asked whether Mr Tweddell had experienced any difficulty in making the flexible joints water-tight, under such immense pressure as 1,500 lbs. to the square inch?

Mr TWEDDELL replied that he had not, and said he would bring specimens of the joints to the next meeting.

The PRESIDENT said that before they adjourned the discussion he would ask them to award a very hearty vote of thanks to Mr Tweddell for the paper brought before them. There was not the least doubt that they were not ignorant of the advantages of hydraulic rivetting; but there were various ways of doing this and various machines employed which were new to some of them; and Mr Tweddell had described these in a very interesting manner. He therefore thought it their duty to pass a vote of thanks to Mr Tweddell for his paper.

The vote was accorded, and the discussion was adjourned till next ordinary meeting.

The discussion of this paper was resumed on the 23rd November, 1880.

On the invitation of the President,

Mr TWEDDELL made a few supplementary remarks to his paper. His (Mr Tweddell's) attention had been drawn to the fact that he had not referred in his paper to several other adaptations of hydraulic power. One of these was its suitability for rotary machines. It has for a long time been successfully applied in various ways to capstans, but as this class of machinery is not included in the scope of this paper, he only mentioned this now because of its applicability in a similar manner to rotary tools, as was in fact proposed by him in a paper read before the Institution of Mechanical Engineers at Cardiff in 1873. In many cases, even for driving shafting, he believed there was an ample margin for its economical application, and such had now been rendered more probable by improvements similar to those introduced by Mr Hastie and described in a paper read by him a year ago in this city. He had not described in any detail sundry schemes having for their objects the more economical use of water in rivetting machines, these have generally taken the shape of toggle joints and such arrangements, but as far as his own experience went, he believed they had not proved successful, nor did he think they ever would be of any practical advantage. The flanging press of Mr Brown, patented by him in 1875, should have been mentioned after the description of the Piedbœuf and other earlier forms of presses, but as Mr Brown was present he could himself give them an account of the advantages he claimed for his design. He regretted these omissions; he had endeavoured as far as he could to refer in his paper to all who had taken part in this branch of hydraulic machinery, but the fact of the paper having to be written somewhat hurriedly must be accepted as an excuse.

Mr A. B. BROWN, drew attention to the subject of the pressure of water as stated in the paper. He alluded to the Bramah pressure of two to five tons per square inch, the Armstrong pressure of 750 lbs., and the intermediate pressure of 1,500 lbs. employed by Mr Tweddell. The Bramah pressure was safe because of the short pipes employed

and the great strength of the different parts. For long lines of pipes, as in a dock or workshop, he considered that there was only one successful pressure, and that was Armstrong's 750 lbs., which was proved by thousands of examples; besides with this pressure india-rubber pipes could be cheaply manufactured having coils of hard brass wire, and giving excellent results. On the other hand, with 1,500 lbs. it was necessary to employ largely cup leathers, whereas with the lower pressure ordinary hemp packing sufficed. He was aware that hemp packing could be used with pressures of 1,500 lbs., but only with excessive friction. In good hydraulic practice the factor of safety was ten, the test factor three, the working pressure being one. The author of the paper stated his objection to the momentum of fly-wheels acting through gearing for the purpose of rivetting, and at the same time advocated the use of momentum by a percussive accumulator in which the working pressure was intermittently raised from 30 to 40 per cent. Now what was bad in the one case was equally bad in the other; and, moreover, it could be seen that the percussive accumulator having delivered its blows rebounded by the elasticity of the water and pipes and thereby slackened off the pressure when it was most required, and afterwards settled to its statical pressure. As the percussive force was proportionate to the height of fall any two riveters working simultaneously would aggravate the danger of bursting or breakage. So impressed was Sir Wm. Armstrong with the dangerous features of momentum that he had carefully fitted all his pressure mains with momentum valves, and to eliminate further the momentum of the weights on the levers of these valves he placed inside these a spiral spring so that the valve might rise without having to set the weight in motion. The author of the paper had noticed a steam accumulator patented by Mr Michael Scott, and declared it to be expensive and otherwise undesirable. In Michael Scott's patent, however, there was no steam accumulator described, but simply a differential hydraulic press in which mention was made that steam might be used in place of water. He had, however, carried out over 50 examples of steam accumulators of

large size, which were found to be much cheaper than the load accumulator, and particularly where cast-iron weights were used, as shown by the author of the paper. A steam accumulator loaded to 80 tons, having an 8 feet stroke, with compound surface condensing engines of 150 indicated H.P. weighed only 24 tons, and this required an exceedingly small foundation, costing no more than £20. In this accumulator momentum was almost entirely eliminated, as the piston and hydraulic ram weighed only 1½ tons, so that the accumulator might descend throughout its entire stroke without raising the pressure more than eight per cent. An example of such ordinary machinery, he stated, could be seen at work at the Bute Docks, Cardiff, where the water was pumped at 750 lbs. per square inch for the sum of 4d per 1,000 gallons expenditure for coal burned. The author's reference to freezing he considered quite erroneous, as a man exerting himself in cold weather in attendance on machinery certainly gets warmer while the machine might be freezing up, and nothing short of charging the whole system with non-freezing fluid would meet the exigencies of our climate. With high pressures such as 1,500 to 2,000 lbs. leathers must be largely used, and in point of fact the drawings of the machinery shown by the author almost without exception indicate leathers in stuffing boxes. There were several cheap non-freezing salts, but they are more or less detrimental to leathers, and in the case of leakages the non-freezing fluid run to waste. His boiler works were exclusively worked by hydraulic machinery, and he had to remove in every case the leathers where the non-freezing fluid was used, but as his pressure was only 700 lbs. they had been replaced by hemp packing. With hydraulic machinery so packed and with a low pressure it was easy to use a cheap non-freezing fluid, and all the pipe connections and different parts of the machinery could be made of ordinary and cheap materials, and if momentum was eliminated and only statical pressures used the best commercial results would be obtained.

Mr JAMES HAMILTON, jun., said that the firm with which he was connected had adopted Mr Tweddell's plan of high pressure; and he might say that it was of the greatest importance to have a good non-

freezing fluid. Yesterday one of their machines became frozen while in use. He had tried one part of glycerine to two parts of water as a non-freezing mixture, but this became frozen in a short time. Now, as it required about 43 gallons to charge their small system of pipes, and as he believed it would require equal quantities of glycerine and water to prevent freezing, it would cost about £13 for the amount of glycerine required. He was sorry that Mr Brown had nothing better to suggest as an antidote to freezing than a mixture of salt, which would affect the leathers. He thought that the use of leathers was a defect in hydraulic machines, as the leathers gave trouble. Referring to machine represented by Fig. 6, the effect of putting in the rivets by the top would be either to break down the ram or crane. He knew their men preferred to put the rivets up from the bottom rather than run the risk of breaking down the machine, but this involved an extra hand. They had that day started a machine for flanging keel plates, which was, he believed, the latest adaptation of hydraulics.

Mr CHARLES R. HARVEY drew attention to the statement in the paper in which the "Accumulator" was claimed as the invention of Sir William Armstrong in 1849 or 1850; he, however, gave a quotation from the *Glasgow Mechanics' Magazine* of 1831, showing that at that time such an apparatus was in use in the works at Barrowfield, Glasgow, of Messrs Henry Monteith & Co., the invention of their manager, Mr George Rodger, in 1818. He also stated that he had called upon Mr Jack at the works recently, and that gentleman had accurately described the apparatus in accordance with Sir Wm. Armstrong's "invention." Mr Jack stated that these machines were called "accumulators" in his time; so that even in the name Sir William had not the merit of originality. He understood, also, that Sir William Armstrong was communicated with on the subject when he took out his patent for it.

Mr JOHN HASTIE said that having had a good deal of experience with high hydraulic pressures—viz., from three to four tons on the square inch—he was at a loss to understand Mr Brown's remarks as to the difficulties experienced when there was any great length of

piping between the pumps and the ram; in distances up to 300 feet he had not found any difficulty. In these cases the pipes were not affected by the frost, being enclosed in wood boxes filled with charcoal, and buried about a foot below the ground. He was rather disappointed that Mr Tweddell's paper did not embrace a wider range of applications, as from the title of it he had expected that reference would have been made to hydraulics as applied to planing, slotting, and other machine tools. Regarding the question of the comparative value of the hydraulic system for distributing power as compared with shafting, he thought Mr Tweddell's published information that the power consumed by shafting was 15 per cent. of the total engine power, to be under the mark; it might be this with the shafting running light, but he was satisfied it would be much more than this while work was being done. The exact co-efficient of efficiency of machinery was difficult to be got at, and was, he believed, much more than was generally assumed. In the case of cargo winches on board ship, when the power was distributed by steam through pipes, the useful work done was only found to be 35 per cent of the power applied.

Mr JAMES M. BLAIR said his firm had some experience with rivetting machines, with both low and high pressures. He differed somewhat from Mr Brown in his experience of india-rubber pipes. They had them in use in low pressure rivetters, but had discarded them, not from bursting, but because they always got into the way, and it was found that they did not bend any more readily than the copper pipes, which were more serviceable even in low pressure machines than the india-rubber. Of course, india-rubber pipes could stand the pressure; but they had discontinued their use from the rapid tear and wear they sustained. He thought the 1,500 lbs. pressure was preferable with their kind of work to a lower pressure. He was of opinion that the machines of Mr Tweddell were very carefully designed and suited the purposes intended admirably. He could testify to the work done at his works as being as satisfactory as stated in the paper.

Mr E. KEMP said that with regard to Mr Brown's remarks as to

the difficulty of keeping the accumulator properly packed with ordinary gaskin, when using a pressure of 1,500 lbs., he could give his testimony to the fact that an accumulator, although started with leather packing, had been fitted with ordinary gaskin, and that it had worked with a falling weight quite successfully for eight years.

Mr MANSEL, in answer to the President, said that unfortunately he had had no experience with hydraulic rivetters. He had machines fitted up, but from the recent severe frost he was not able to use them, and had been compelled to fall back in the meantime on hand rivetting; so it would probably be a little while before he could give an opinion on hydraulic rivetting.

Mr DAVID JOHNSTONE said that ten years ago he had shown the advantages of hydraulic power for boring machines, and had adopted the principle of the accumulator independently. A great deal of forging could be done with hydraulic pressure, especially with light weights and particularly in steel. He had also advocated the use of hydraulic power for drilling machines, especially where a number of holes were required to be bored at once. He would have the drills stationary and raise the bed by hydraulic rams, which would have the effect of making the drills rigid. He had recommended the use of *lignum vitæ* for pump packing of pistons some time ago, which was far cheaper than cup leathers or any other packing that had been tried.

Mr DRUMMOND said they had had hydraulic machines for a year in operation and had found the hydraulic press of great use in the forging of waggon wheels instead of the steam hammer. They had also used it in flanging boiler plates with great satisfaction. They used to take about three days to complete the flanging for a locomotive boiler, but they now completed it in little more than three hours. They had also used it in rivetting, and he was of opinion that hydraulic power was most effective for the purposes of forging and in reducing the cost of labour very greatly.

Mr A. B. BROWN said what he meant by long lines of piping was about a mile in length. He believed he had half-a-mile of pipes in his works, and when they came to have such long lines of pipes such

pressure as Mr Tweddell advocated had a tendency to straighten the bends and consequently leave all the joints worse, which was not the case with a lower pressure. Then with regard to india-rubber piping, it should be coiled on a drum, and he believed that india-rubber piping so hung, was certainly preferable to copper pipes with those numerous joints, each joint requiring two cup leathers.

Mr TWEDDELL in reply to the discussion, said that he had read his paper at the worst possible time of year, considering that they were experiencing 24 degress of frost; but it would never do to be beaten by frost or anything else, and certainly they might rely upon overcoming, in time, all the difficulties referred to that evening. Mr Brown had asked why he had chosen 1,500 lbs. per square inch as a working pressure; there were a great many reasons why he had done so, but nothing had confirmed him more in its use than the fact that Sir Wm. Armstrong's own firm adopted it, when they used his (Mr Tweddell's) machines, and this when their own pressure of 750 lbs. was laid already over all their works. So far from any tendency existing to lower the pressure, Messrs Sellers & Co., his licensees in the United States, had adopted 2,000 lbs. per square inch, and had he to begin again, he would as soon use one ton per square inch as 1,500 lbs. There were other reasons in its favour also, but its successful working in hundreds of machines was the best *practical* proof of its suitability. If, as Mr Brown said, all the benefits of percussive force were neutralised by the elasticity of the iron pipes, if 1,500 lbs. per square inch did so act on iron or copper pipes, how much more must this result obtain when india-rubber pipes are used, even with 700 lbs. pressure only. In reference to his remark that when two riveters draw on the accumulator at once the danger of bursting would be aggravated, the same argument would apply if several dock gates or capstans were started at any one moment. He had heard nothing that evening to shake his confidence in high pressure, and his experience had been very satisfactorily confirmed by Mr J. M. Blair and other speakers who had worked it for years. He was also satisfied that there was no question as to the superiority of copper pipes over india-rubber,

and when Mr Brown had to strengthen his by coiling brass wire round it, he thought he was getting next door to using copper himself. As regarded the proposal to coil india-rubber pipes round a drum, he did not think that it would answer; it had been already patented, and it was, he believed an American idea; perhaps Mr Brown had had experience in its use. A pressure of 1,500 lbs. per square inch possessed also the minor but still useful advantage that it was handy for rough calculations; it was approximately 100 atmospheres per square inch, and each gallon pumped per minute represented very nearly one horse-power. These were small advantages, but as they were obtained without any *disadvantages* they were worth something. The fact is, there is no such thing as *one* right pressure; each circumstance or application requires separate treatment. With regard to the dimensions of the pipes, Mr Brown had stated that the life of a pipe was in the inverse ratio to its size, from which it clearly followed that the smaller the pipe, the longer its life, a fact he could confirm, and since by using 1,500 lbs. a pipe half the size would convey the same power, this was also a very decided point in favour of higher pressure. There was no observable increase in the friction between hemp packing at 1,500 lbs. per square inch and at 750 lbs. per square inch, and he had made numerous experiments to try this. There was no doubt that hemp packing was less affected by salts held in solution as used in endeavouring to avoid the effects of frosts. The effect of the various salts and acids on leathers had, he thought, been exaggerated, but he had so far only used glycerine or methylated spirits, and when gun metal could be employed he used nothing but leather. It had been found in hydraulic railway brakes that the better qualities of salt prevented freezing, without in any way injuring the leathers working in gun metal. Another argument in favour of the higher pressure was, that it was more difficult to freeze water under a pressure of 1,500 lbs. than at 750 lbs. The fact of the matter was they might just as well give up the use of rivers because they froze up in the winter, as to give up the use of hydraulic machines because they were apt to be affected by the state of the

thermometer for a fractional part of the working year; they must endeavour to get machines so efficient that they will still pay, even if laid off for a day or two in very extreme weather. Mr Brown had referred to the number of joints shown on one of the diagrams as required when copper pipe is used. He would point out that this represented a scheme of his many years old and was referred to on historical grounds only; he did not use now such an arrangement as there illustrated, but in Figs. 5 and 6 the plans now used are fully shown. There are other modes of working not shown on the diagrams, one of which, suggested and applied by Mr Hamilton, was as follows:—He used a long boom or lever, having the rivetter on one end and a balance weight at the other; in this case there was not a single swivel joint used; he therefore maintained that a high pressure of water need not even necessitate a number of swivel joints, or more couplings than are needed when india-rubber pipe is used, nor was there necessity for two cup leathers in every swivel joint. Then as to the price of glycerine, Mr Hamilton had certainly said he had bought it at 12s a gallon, but he (Mr Tweddell) could purchase it of a suitable quality for 2s 8d. He had made many experiments as to freezing mixtures, but there was ample room for more information on this head. So far the liability of freezing had not affected the extension of other hydraulic machinery, and he did not think it would do so in the case of hydraulic machine tools. As regarded the steam accumulator he was perfectly astounded at the economical results arrived at by Mr Brown, namely, that they could get 1000 gallons of water at 750 lbs. per square inch pumped for 4d. If this is so it was indeed satisfactory and could only increase the uses for hydraulic power, even supposing that results so different from any hitherto recorded were due to the use of the steam accumulator, which he did not think possible. In respect to the foundations required, he could not agree with Mr Brown. That gentleman said there was a great saving with the steam accumulator in the cost of foundations, but if he would look at Fig. 7 he would see there was no foundation at all required, and even in ordinary cases the foundations required are very small. Then

again as to the observations as to momentum valves and the precautions against the percussive action of the accumulator, he could only say that they had been successful in practice, that the pipes and all parts were properly proportioned to stand the maximum pressure ever attained, and that he only advocated percussive power in certain cases. By its means rivets of from $1\frac{1}{4}$ inches to $1\frac{1}{2}$ inches diameter in plates $1\frac{1}{8}$ inch thick had been put in by a very small accumulator, where otherwise huge and clumsy ones with enormous dead weights would have been necessary. There was no question that the combination of the two forces of blow and pressure had acted well, and it had been proved by some hundreds of successful applications in practice. In regard to the application of hydraulic power to garboard plate-bending mentioned by Mr Hamilton, he might say that although he had not yet made any hydraulic machine for that purpose, he had submitted plans some years ago to the French Government, and he had hopes of their practical introduction soon. Mr Harvey referred to the invention of an accumulator in 1818 which was interesting as an historical fact, although he had himself alluded in his paper to a press used in a similar manner at a very early period in London. In reference to Mr Hastie's remarks he might say that he wished to confine himself to machines in most general use, and he quite endorsed his opinion, that even when all the objections usually raised against hydraulic machinery are allowed for, there are, on the other hand, so many advantages that, taking full account of both, there is a great field open even for its application to rotary purposes. This he had long maintained, and there is an ample field for all to make experiments. With reference to Mr Johnston's remarks about the use of hydraulic power for raising the beds of drilling machines, this had been done for many years. It would be interesting to know how the *lignum vitæ* packing referred to had answered in practice, and what pressure it was subjected to. He was sorry that time had prevented his going more into the subject of forging by hydraulic power, but he exhibited some samples on the table to the meeting. As Mr Drummoned had remarked, it would be very interesting and profit-

able to hear what others had done in it. He had to thank them for the kind manner in which they had received his paper.

The PRESIDENT said this most interesting discussion had called forth remarks from several of those present who had had considerable experience on the subject; and it was evident that hydraulic power bade fair in a short time to be a very important element in their workshops. What application of it they had at present was merely a forecast of what would be in the future. He thought they must all feel indebted to Mr Tweddell for coming from London to be present at the discussion, and although they had given him a hearty vote of thanks for his paper at last meeting, they had a right to thank him for his attendance and explanations that evening.

The vote was unanimously awarded.

On Screw Nuts with Differential Threads and some Applications of Same

By Mr JOHN HASTIE.

(SEE PLATE IV.)

Received and Read 23rd November, 1880.

IN executing repairs, difficulties are frequently experienced in taking machinery to pieces, particularly in separating rods from pistons and crossheads, propellers from shafts, and pins from cranks, and in order to provide a remedy for this the author has designed and patented a nut which, while effectually removing this difficulty, gives additional facilities in securing the various parts together. This nut is illustrated in its simplest form by Fig. 1 which shows a piston and rod with this attachment. The nut A is screwed internally with the usual Whitworth thread to fit the screw on end of rod B—externally part of the nut is screwed with a thread slightly finer in the pitch than the internal thread. In practice the difference found handiest is a tenth. The body of piston C is screwed internally to fit the outer thread of nut. The nut is entered first on the piston rod, then the outer thread is entered into the piston block, and in being screwed home, draws the piston rod into its place at a tenth part of the speed with which the nut is itself being screwed into piston block. With this arrangement, if a spanner of the usual length is being employed, the rod is drawn into its place with about ten times the power of the ordinary nut, or the same amount of power with a key of about a tenth part of the length, a matter of considerable importance where it is necessary to use a box spanner. When the rod is screwed hard in its place, a space equal to two or three threads is left between end

of nut and metal of piston; the intention of this is that the strain should be entirely borne by the threads. When this is done the nut attachment becomes practically a rivet on account of the small angle at which the differential threads lie to each other. This is shown by Fig. 2, which shows the angle of thread of a bolt 2½ inches diameter, this forms an incline of 1 in 31·5. The inner line shows the angle of the outer thread of differential nut for this diameter of bolt. When the strain is entirely borne on the threads the retaining angle is one-tenth of what it would be in the case of an ordinary nut, or an inclination of 1 in 315, an angle so fine as to render it impossible for the nut to slip back. This angle being as fine as could be obtained with a screw having 40 threads to the inch, instead of 4 threads according to Whitworth's table. To remove the rod from piston the nut has only to be screwed back and the differential action of the threads not only gives a positive force in pushing the rod out, but a force equal to what could be obtained by the application of a hydraulic jack.

Various applications suggest themselves in the application of this principle, and a few of these are shown on the drawings exhibited. Fig. 2 shows a pump plunger where the use of a box spanner becomes necessary. Fig. 3 shows the nut applied to propellers. Fig. 4, the nut as applied to hydraulic capstan at present being manufactured for the Greenock Harbour Trustees by the author's firm. Fig. 5 shows the application to engine bearings. The particular case shown being a connecting rod end, the advantage of this application is fineness of adjustment, a thorough locking arrangement in any position, and a positive power in separating the bushes, on account of the great power obtained by the differential threads. By using narrow liners of soft metal the wear of a journal could be taken up by the abrasion of the metal forming the liner.

In all the illustrations we have shown the internal screw for outer thread of nut is cut out of the body of the piece into which it is screwed. This, however, is not a necessity, as a separate nut can be made and pinned or rivetted on it.

Fig. 4 shows the application of this nut for use instead of ordinary nuts, for situations where either great power in drawing the parts together, or greater security in locking, is required. In this case the outer nut is screwed as much coarser in the pitch, compared with the inner, as it was finer in the illustrations already given. A narrow washer of copper or any other soft metal is placed between the outer nut and the surface it is being screwed against. Shallow radial grooves are cut both in the nut face and the surface of metal. Before being entered on the bolt the outer and inner nut are screwed together and present the appearance of an ordinary nut. It is then screwed down in the usual way; when the surfaces meet, the inner nut is screwed back, the force applied acting with ten-fold power, and forces the surface of copper washer into the grooves, thus locking it. The inner nut is locked in the same way as the nuts previously referred to.

The only other illustration is the application in the bolting of the fish plates of rails. This has not been applied in practice yet. In this case the fish plate on one side is tapped for the outer thread of nut, and should give a fastening equal to a rivet without adding an additional part to the ordinary arrangement.

Models of the actual applications of these nuts were laid on the table for inspection.

In the after discussion,

Mr KEMP said his attention had been called to the subject of the paper some time ago, and certainly it included a very ingenious mode of getting great power in a compact space. Whether it might yet come into use for all the purposes Mr Hastie suggested he would not like at present to affirm. Certainly there were various reasons why it must be of very great service in fastening fish-jointed rails, for the power of fastening these once and for all would undoubtedly be a great boon to the railway interest. As regarded the application to piston-rod ends he did not know whether it would be of so much advantage as for some other purposes.

Mr BROWN said the arrangement answered exceedingly well with

Richard's indicator. This was evidently a new application of the same principle.

Mr H. R. ROBSON observed that the author of the paper proposed the application of his plan to pistons, propeller nuts, &c.; and while it was true that considerable difficulty had been experienced in securing such parts, more especially in large engines, from the great strain upon them they were apt to get loose. He, however, thought that the plan under consideration would not only be found difficult to fit and adjust in such large parts, but a difficulty might arise from these nuts corroding fast in their place, while in the case of the parts requiring to be taken asunder for repairs, might cause great inconvenience and delay. In his experience it had frequently happened, with ordinary nuts, that they had to be cut off. For smaller bolts about the gearing of engines, or for such fastenings as fish-plates for rails, it might, however, be found to be a good method.

Mr JOHN ROBERTSON said that this was the same principle as was applied in Mr R. D. Napier's friction clutch—one leverage gaining upon the other, being very powerful and yet simple.

Mr MANSEL said that Mr Hastie had proposed a number of very ingenious applications of the principle of the differential action of two screw threads to some important practical uses. This differential action constituted what in books and lectures was known as Hunter's screw.

Mr JOHN HASTIE wished it to be understood that he did not claim the differential screw at all as part of his patent. It was known 40 years ago. It was merely the particular application of it that he claimed.

Mr MORTIMER EVANS asked where such bolts could be got for fish-plates. He had found great difficulty in getting bolts to hold fish-plates securely for any length of time, constant attention and screwing up being necessary, shaking, wear, and rust tending to loosen them in a very short time. If Mr Hastie's bolts could be relied on they would be invaluable. He would be very glad to give them a trial.

On the motion of the PRESIDENT, a vote of thanks was awarded

Mr Hastie for his paper, the further discussion of which was adjourned till next meeting.

The discussion of this paper was resumed on the 21st December, 1880.

The PRESIDENT said Mr Hastie did not claim anything very new but that merely some very nice applications could be made of the principle. He would be glad to hear remarks on this subject from members; or perhaps Mr Hastie had something to add to what he had said at the previous meeting.

Mr JOHN HASTIE said, with reference to Mr Robson's remarks at the last meeting, that he had experienced no difficulty in forming accurately the various parts, where there was the likelihood of corrosion taking place, as in fixing pistons, the nut was made of brass. He might state further regarding these nuts that he had been led to scheme them on account of difficulties experienced with the ordinary nuts in the case of repairs.

In reply to questions from Mr Copestake,

Mr HASTIE stated that the employment of the differential thread did not in any way prevent the outer nut from having a fair bed on the surface of the article which was to be screwed.

Mr WEIR thought this was a most ingenious application of the differential screw principle. He had no doubt it would be very suitable for a great many purposes.

Mr JOHN HASTIE thought it was worth while to call attention to the holding power of it, as shown (see Plate IV.) The greater angle was the ordinary thread, and the least angle was the angle that was formed between the threads, so that, in this way, the nut had almost the power of a rivet. In the instance shown (see Fig. 7), where it was screwed into the part, the larger diameter was the finer thread. The difference between the two angles was only the tenth of an inch. There might be a slip put in that would yield to this. The nut, coming down to the face, did not need a gant on it. It was perfectly fair. They were applying it in various cases, and there was no trouble experienced, nor cases of slipping back.

Mr D. HALLEY said, in using the nuts, as in overhauling engines in port, or making repairs at sea, both of which were generally hurried jobs, there was a chance of the engineer entering the nut on the bolt when the latter was not in proper position, and asked what provision was made for guiding the engineer in this. By entering nut on bolt when out of position, the former might be bottomed before enough depth of thread had been got to give the required strength.

Mr HASTIE stated that the adjustment could be carried on to the same extent as with the ordinary nut—viz., as far as there was screw on the bolt to follow up. In the case of the differential nut, when it was through time screwed home, and further adjustment was required, the nut was unscrewed and re-entered on the cover, when it occupied the same position as at the first.

The PRESIDENT said that it was every engineer's business to get the greatest security possible. The nuts brought before them by Mr Hastie were a considerable improvement on, although more complicated than those generally in use. Of course, as their use led to increased cost, it would be for engineers to judge of their advan tage over the ordinary system. He was sure the Institution were indebted to Mr Hastie for bringing the matter before them.

On Early Clyde Built Steamers.

By Mr W. J. Millar, C.E.

SEE PLATE V.

Read 21st December, 1880.

The object of the present paper is to place on record, in the Transactions of the Institution, certain facts relative to the size and form of the early Clyde steamers, and the power and arrangement of the engines. A good deal of information exists as to these early types of steam vessels, recorded in newspapers and books. It is, however, believed that amongst the members of such an Institution as this, there must be a large amount of valuable experience of such matters, and that such members will willingly contribute what information they have in regard to the early introduction of steam on the Clyde. For many interesting facts in the present paper I am specially indebted to Mr Robert Cook, one of our original members, who has kindly furnished me with notes and sketches.

The subject of the Introduction of Steam Navigation, and its Rise and Progress, is a very wide one, and would require several papers to do it justice. I therefore propose simply to limit myself to the Clyde types of vessels, from the "Comet" downwards, until the use of steam propulsion became general.

Passing over, therefore, the early attempts at steam propulsion made by Miller, Taylor, Symington, and others, we come to the year 1812, when Henry Bell launched his "Comet." The Clyde at that time was a winding shallow stream, filled up largely with sandbanks, and it appears to have been no unusual occurrence then, and for some time afterwards, for the boats plying to Greenock and other

ports, although only drawing at most 5 feet of water, to get aground for an hour or so on a bank, the passengers meanwhile exercising themselves by running from side to side, to get the keel loosened out of the sand.

Looking at the records of those early vessels, and taking the wooden period to start with, we may for convenience group the results under several divisions, viz. :—

1st, The period of river boats strictly speaking—viz., those plying to Greenock and Helensburgh (1812-15).
2nd, The period of river and coasting boats (1815); and
3rd. The period of deep sea steamers (1818).

The boats of 1812 and 1813 appear to have been content to ply to Greenock and Helensburgh as opposition to the coaches and fly-boats on the river.

In 1815 the first trip was made to Rothesay.

In 1816 the Campbeltown route was opened, and a pleasure trip attempted to Londonderry.

In 1818 the Belfast trade was commenced, followed in 1819 by the Liverpool route.

The "Comet" was about 25 tons, built in 1811-12 by John Wood at Port-Glasgow. She measured 42 ft. long, 40 ft. keel, and 11 ft. broad; with 5 ft. 6 in. draft of water. The engine was made by John Robertson, Glasgow, and was a condensing one of 3 H.P., the dia. of cylinder being 11 in., and the stroke 16 in., the crank working below the cylinder; the engine shaft, connected with a fly wheel, is said to have been of cast-iron, and 3½ in. square.

The engine was fitted on board before launching and steam raised. The first trip was from Port-Glasgow to Helensburgh. Afterwards the "Comet" commenced to ply regularly between Glasgow, Greenock, and Helensburgh.

At that time the vessel was fitted with two pairs of paddles (see Figs. 1 & 2), 7 ft. diameter, with spur wheels of 3½ ft. diameter; but shortly afterwards she was lengthened to 60 feet, and a new engine with a single pair of paddles substituted, the speed being now

greatly improved, and reaching from 5 to 6 miles per hour. The diameter of the cylinder is stated as 12½ inches and the H.P. 4.

The career of the "Comet" is well known. She plied on the Forth about 1815, and was afterwards placed on the Fort-William route, and was lost at Craignish in 1820.

The following is extract from the advertisement which was issued of the "Comet's" sailings:—

"The Steamboat Comet, between Glasgow, Greenock, and Helensburgh, for passengers only.—The subscriber, having at much expense fitted up a handsome vessel to ply upon the river Clyde from Glasgow, to sail by the power of air, wind, and steam. He intends that the vessel shall leave the Broomielaw on Tuesdays, Thursdays, and Saturdays, about mid-day, or such an hour thereafter as may answer from the state of the tide; and to leave Greenock on Mondays, Wednesdays, and Fridays, in the morning, to suit the tide. The elegance, comfort, safety, and speed of this vessel require only to be seen to meet the approbation of the public; and the proprietor is determined to do everything in his power to merit general support. The terms are for the present fixed at 4s for the best cabin and 3s for the second, but beyond these rates nothing is to be allowed to servants or any person employed about the vessel.

"HENRY BELL."

"Helensburgh, 5th August, 1812."

The "Elizabeth," 33 tons, the follower of the "Comet," was built in 1812-13, by John Wood. She measured 58 ft. long over all, 51 ft. keel, 12 ft. beam, and 5 ft. deep. The engine was by James Cook of Tradeston, Glasgow, and of 10 H.P. The following copy of an advertisement in reference to this steamer is given in a work on "Steam and Steam Navigation," by J. Scott Russell.

"The 'Elizabeth' was started for passengers on the 9th of March, 1813, and has continued to run from Glasgow to Greenock daily, leaving Glasgow in the morning, and returning the same evening. The passage, which is twenty-seven miles, has been made with a hundred passengers on board, in something less than four hours, and in favourable circumstances in two hours and three-quarters. The

'Elizabeth' has sailed eighty-one miles in one day, at an average of *nine miles an hour.*

"The 'Elizabeth' measures aloft fifty-eight feet; the best cabin is twenty-one feet long, eleven feet three at midships, and nine feet four inches aft, seated all round, and covered with handsome carpeting; a sofa, clothed with marone, is placed at one end of the cabin, and gives the whole a warm and cheerful appearance. There are twelve small windows, each finished with marone curtains, with tassels, fringes, and velvet cornices, ornamented with gilt ornaments, having altogether a very rich effect. Above the sofa there is a large mirror suspended, and at each side book-shelves are placed, containing a collection of the best authors, for the amusement and edification of those who may avail themselves of them during the passage—other amusements are likewise to be had on board.

"The engine stands amidships, and requires a considerable space in length, and all the breadth of the vessel. The forecastle, which is rather small, is about eleven feet six by nine feet six inches, not quite so comfortable as the after one, but well calculated for a cold day, and by no means disagreeable in a warm one; all the windows in both the cabins are made in such a way as to shift up and down like those of a coach, admitting a very free circulation of fresh air. From the height of the roofs of both cabins, which are about seven feet four inches, they will be extremely pleasant and healthful in the summer months for those who may favour the boat in parties of pleasure.

"Already the public advantages of this mode of conveyance have been generally acknowledged; indeed, it may without exaggeration be said, that the intercourse, through the medium of the steamboats, between Glasgow and Greenock, has, comparatively speaking, brought these places ten or twelve miles nearer to each other. In most cases the passages are made in the same time as by the coaches; and they have been, in numerous instances, done with greater rapidity. In comparing the comfortableness of these conveyances, the preference will be given decidedly to the steamboat. Besides all this, a great saving, in point of expense, is produced;

the fare in the best cabin being only four shillings, and in the inferior one two shillings and sixpence; whereas the inside of a coach costs not less than twelve shillings, and the outside eight shillings."

The "Clyde," 69 tons, was also built by John Wood. She was 76 ft. long over all, 72 ft. keel, by 14 ft. beam, and depth of hold of 7½ ft. The engine was made by John Robertson; the cylinder was 22 in. diameter, with a 2-foot stroke, and of 14 H.P. The speed attained was 6 miles per hour.

The "Glasgow," 74 tons, was built by John Wood, and was 72 ft. long by 15 ft. beam. The engine, of 16 H.P. (side lever), cylinder 20 in. diameter, stroke 2 ft., was made by James Cook. This vessel ran to Largs and Millport, and must have been the first boat on this station. She could run to Greenock with the tide in 2 hours and 10 minutes.

The forms of these early steamers are more or less similar to those shown by Figs. 3, 4, and 5.

In 1814, six steamers appear to have been built—viz., the "Industry," "Trusty," "Princess Charlotte," "Prince of Orange," "Marjory," and "Argyle."

As we have the "Industry" still amongst us, although now becoming broken up, she may be referred to particularly, as affording a link between these early times and the present.

The "Industry" (see Figs. 5 and 6), 55 tons, was built in 1814, it is said at Fairlie, and from the first, with the "Trusty" (wrecked in the Clyde), plied as a luggage boat between Glasgow and Greenock. The engine was by Mr Thomson of Tradeston, Glasgow, and has the peculiarity common to the earlier boats of being fitted with spur wheels to connect the engine with the paddles (see Fig. 7).

The "Industry" was plying on the river till about 10 years ago, and now lies in the harbour at Bowling.

The "Princess Charlotte" and "Prince of Orange" were built by Mr Munn of Greenock, and engined by Boulton & Watt.

The "Marjory" was built at Dumbarton by William Denny, and engined by James Cook, with a single side lever engine of 10 H.P

This vessel was sent to the Thames about 1815. Her dimensions were 63 ft. long by 12 ft. beam.

The "Argyle," 78 tons, was built at Port-Glasgow, and engined by James Cook, with a single side lever engine of 14 H.P. She was a similar vessel to the "Albion," and appears to have gone to the Thames in 1815.

In 1815 other six steamers appear to have been added, viz., the "Waterloo," "Argyle" No. 2, "Greenock," "Caledonia," "Dumbarton Castle," and "Britannia."

The "Waterloo," 90 tons, was built and launched after the celebrated battle was fought, and was similar to the "Argyle." She plied on the Helensburgh station.

The engines were by James Cook, and of 20 H.P.

The "Greenock," 62 tons 10 H.P., appears to have been built by Archibald M'Lauchlan at Dumbarton.

The "Caledonia," 102 tons, was built by Messrs Wood, Port-Glasgow. She measured 95 ft. 6 in. long by 15 ft. beam, draft 4½ ft. to 5 ft., and had two engines of 16 H.P. each, made by the Greenhead Foundry Co. This vessel was sold in 1816 for the Thames and was afterwards placed on the Rhine.

The "Dumbarton Castle," 81 tons 32 H.P. (two of 16 H.P. each), built by Archibald M'Lauchlan, Dumbarton, and engined by Duncan M'Arthur & Co., Camlachie, was the first steamer to make a trip to Rothesay, and the event marked by the presentation of a handsome punch-bowl to the captain, James Johnston. This vessel appears to have been wrecked in the Clyde in 1829.

The "Britannia," 109 tons 32 H.P., with a draft of 4 ft. 6 in., measured about 80 ft. long by 16 ft. beam. Her engines were made by James Cook, and consisted of a pair of beam engines and spur wheels to raise the power to the paddle shaft, similar to those of the second "Waterloo." (See Fig. 8.) The cylinders were 20 in. diameter, with 2 ft. 6 in. stroke.

This vessel plied to Campbeltown and made a trip to Londonderry, thereby opening up the trade with the latter port. She appears to have been wrecked off Donaghadee in 1829.

The following is copy of an advertisement appearing in the *Glasgow Herald* of June, 1815:—"The proprietors of the Britannia steamboat beg leave to inform the public that she, according to advertisement, performed her voyage to Largs, Rothesay, and Campbeltown, and returned in such a short time, and gave so great satisfaction, that, owing to an agreement with the public of Campbeltown, they will be under the necessity of abandoning the voyage to Inveraray, as advertised for to-morrow, but will upon Monday first, at ten o'clock, sail for Greenock, Gourock, Rothesay, and Campbeltown, and return on Wednesday. As the voyage is far, the passengers will be accommodated with refreshments, suitable and agreeable for them."

In 1816 we have further additions, viz., the "Neptune," "Albion," "Rothesay Castle," "Lord Nelson," "Lady of the Lake," "Duke of Wellington."

Of these the "Albion," 92 tons, was built by J. Wood, and measured about 70 ft. by 13 ft. beam, with draft of 4 ft. The engine (side-lever) of 20 H.P. was by James Cook, the cylinder being 22 in. diameter, with a 2 ft. stroke. She plied to Largs.

The cost of this vessel is stated as—

Hull, . . .	£1,000
Engines, . .	1,600
Fittings, . .	850
	£3,450

The "Lady of the Lake," engined by James Cook with a single side lever engine, appears to have been transferred to the Frith of Forth, and after plying there was sent to the Elbe, but was afterwards brought back.

In 1817 only two boats appear to have been added, viz., the "Marion" and the "Defiance." Of these the "Marion" appears to have been the first steamer on Loch Lomond, when she plied in 1820 in connection with the Post Boy steamer from Glasgow.

The year 1818 brought several additions, viz., the "Rob Roy," "Marquis of Bute," "Woodford," "Active" and "Despatch." Of

these the "Rob Roy" is the most interesting, as she was the first steamer to ply to Belfast.

The "Rob Roy" was 90 tons and of 30 H.P., with a draft of 7 ft., and was built by William Denny, at Dumbarton, and engined with a single side lever engine by David Napier, and after plying some years on the Belfast route was transferred to the Dover and Calais service.

Previous to starting this steamer it is said that Mr Napier crossed to Belfast during a storm in a sailing vessel and watching the effect of the waves was convinced steam could be utilised to overcome them. He then by means of experiments on model boats determined to give his proposed steamer a sharper entrance at the bow than was at that time common for the river steamers.

In 1819 Mr David Napier had the "Talbot" built for him by Messrs Wood. She was 150 tons, and had two of Mr Napier's engines of 30 H.P. each. The "Talbot" plied between Holyhead and Dublin and appears to have been a very complete and efficient vessel. Another vessel, the "Ivanhoe," was added to this route. She was 170 tons burthen, built by Scott of Greenock and engined by Mr D. Napier with engines of 60 H.P.

In the same year Mr D. Napier established the first line of steamers between Glasgow and Liverpool, the "Robert Bruce" of 150 tons and 60 H.P. being the first to start. She was built by Messrs Wood and engined by Mr D. Napier. Two others were added, viz., the "Superb," in 1820, of 240 tons and 70 H.P., and the "Eclipse," in 1821, of 240 tons and 60 H.P. The former was built by Scott and the latter by Steele of Greenock, the engines in both cases being by Mr D. Napier. The following notice of the "Superb" appears in the *Steamboat Companion* for 1820:—"The 'Superb' is at this moment the finest, largest, and most powerful steam vessel in Britain. She registers 241 tons and is impelled by two very fine engines of 36 H.P. each, to which copper boilers are attached. The average duration of the passage from the Clyde to Liverpool does not exceed 30 hours. Fare, £2 15s."

The "Fingal," 67 tons and 16 H.P., and the "Robert Burns,"

66 tons and 20 H.P., were added to the river steamers; the former appears to have been engined by James Cook and the latter by David Napier.

The second "Waterloo" was built in this year by Scott of Greenock and engined by James Cook. She measured about 120 ft. long by 22 ft. beam, and had two beam engines with 30-inch cylinders and 3 ft. stroke with spur wheels to connect the paddle shaft with the engines. (See Fig. 8.) She plied between Belfast and Liverpool.

The first tugboat on the river, the "Samson," was also launched in 1819. She had two engines of 20 H.P. each, by Duncan M'Arthur (whose works were at foot of Washington Street and afterwards became the property of Mr Robert Napier). The "Samson" was also fitted up for passengers.

The year 1820, besides adding the "Superb," already mentioned, brought the "Inveraray Castle," "Post Boy," "Rapid," and "Dumbarton." According to Scott's Memorabilia, the "Oscar" was also added this year; the date given in the *Steamboat Companion* is 1816, the H.P. being stated as 12 and the draft 3 ft. 2 in.

The "Inveraray Castle," 70 tons, the first of this name, was, of course, a wooden boat, with the "Rothesay" and "Toward Castles," 74 and 79 tons respectively, added in later years—and belonging to the Highland Steamboat Co.—plied to Inveraray, Rothesay, and Arran. I am told by a gentleman who sailed in this vessel that she had two boilers and the engines had conical valves, with wind and tide they would get to Rothesay in about four hours, and that the steamer generally lay over night at Ardrishaig *en route* to Inveraray. She was engined by Duncan M'Arthur.

The "Dunoon Castle," 100 tons, was, I believe, the last of the wooden boats of the Castle Co. I cannot find when she was built but remember sailing in her about 28 years ago. She plied to Inveraray, and was broken up probably 25 years ago above Glasgow Bridge. This vessel would be the last wooden passenger steamer on the Clyde.

The "Post Boy," 65 tons 20 H.P., and 3 ft. draft of water, was

the first steamer to leave the Broomielaw at a fixed hour regardless of the tide, and started at 6 A.M. for Dumbarton in connection with the "Marion" plying on Loch Lomond.

Mr D. Napier appears to have tried a surface condenser on board this boat, consisting of a series of small copper tubes through which the steam passed, and was condensed by a circulation of cold water on the outside of the tubes.

The "Rapid" was 136 tons 40 H.P. with 7 ft. draft and plied to Liverpool and Belfast.

The "Dumbarton," 65 tons 25 H.P., 3 ft. 5 in. draft, plied on the river.

In 1821 we have "Comet" No. 2, which was built for Henry Bell and others for the West Highland route. She came into collision with the Ayr steamer off Gourock on 20th October, 1825, and went down with the loss of 70 persons. The vessel was raised and subsequently made into a lighter. Some years ago a notice appeared in the daily papers of the lighter "Ann" which had gone ashore in a gale of wind at Port-Glasgow and that this was the same "Comet" lengthened and fitted out as a sailing vessel.

The "Eclipse," already mentioned, was also added this year. Besides these we have the "Majestic," "Caledonia," and "Highlander."

The "Majestic" was 350 tons, 100 H.P., and had two engines; the speed was ten miles.

In 1822 the "James Watt," 448 tons, appears to have been built by Messrs Wood, and had two engines by Boulton & Watt of 50 H.P. each, speed 10 miles. This vessel had spur gearing, the engine shaft making the greater number of revolutions. She measured 146 ft. long by 25 ft. beam, and plied between Leith and London.

The "City of Glasgow," 183 tons, with two engines of 50 H.P., appears to have plied to Liverpool, sailing on the Fridays. The "Hercules," a tug of 74 tons, the "Largs," 83 tons, and the "Toward Castle," 79 tons, river boats, appear to have been added in the year 1822.

Some years later a steam ship, considered large for the time,

called "The United Kingdom," measuring 160 ft. long, 26½ ft. beam, and 200 H.P., was built by Steele of Greenock and engined by D. Napier.

In 1824 the steamer "Leven" was engined by Mr Robert Napier. The engine (which was the first marine engine made by Mr Napier) was a side lever one, and may still be seen standing in well-merited repose on a pedestal at the head of Dumbarton River Pier and beneath the shadow of the celebrated rock. The "Leven" appears to have been 54 tons and plied to Dumbarton.

Having thus traversed the first decade of the steam shipbuilding on the Clyde we find the success of the new method of propulsion firmly established, not only for river and coasting traffic, but for the deep sea service.

These vessels were as yet of wood and were of great breadth to their length, the proportions appearing to vary from the "Comet" of about four times the beam, to the "United Kingdom" of about six times the beam.

Even as early as the year 1825 the Indian ocean had been traversed by a steam vessel named the "Enterprize," of about 500 tons and 120 H.P., and built and engined on the Thames.

The iron period of steam shipbuilding appears to date from 1821, when the "Aaron Manby" was made in parts at Horsley and put together at London.

The first iron steamer built on the Clyde was "Aglaia," in 1827. She was 30 tons, and plied on Loch Eck.

The first iron steamer to ply on the Clyde was the "Fairy Queen" of 40 tons, built at the Old Basin, and brought down to the river and launched in 1831. This vessel plied to Largs and Millport in 1836.

The substitution of iron for wood was, however, tried in our neighbourhood at an earlier date,* as the "Vulcan," built of iron plates, with flat bar frames, appears to have been designed by Sir John

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* See Paper by Mr Archd. Gilchrist, Proceedings Scottish Shipbuilders' Association, Session 1864-65.

Robinson, of Edinburgh, in 1816, and was built at Faskine, on the Monkland Canal, in 1818, by Thomas Wilson. She commenced plying on the Forth and Clyde Canal as a passage boat in 1819.

The "Royal Sovereign," built in 1839, was the first iron sea-going steamer. She plied between Glasgow and Liverpool, and was built and engined by Messrs Tod & M'Gregor. The same firm afterwards built the "Royal George" in 1839, and the "Princess Royal" in 1841.

The first iron screw steamer built at Glasgow was the "Fire Queen," in 1845. She was 135 tons, and 80 H.P.

The first iron screw steamer to ply between Glasgow and New York was the "City of Glasgow," of 1609 tons; built by Tod & M'Gregor in 1850.

The first paddle steamer to cross the Atlantic from Britain was the "Sirius," built in 1837 by Messrs Menzies & Son, of Leith, and engined by Messrs T. Wingate & Co., of Glasgow. The "Great Western," built at Bristol, also made the passage—the two arriving in New York about the same time. The "Sirius" measured 178 ft. long by 25 ft. 8 in. beam, depth 18 ft. 3 in., and 450 tons register. She was fitted with two side lever engines of 270 H.P.; diameter of cylinder 60 in., stroke 6 ft., paddle wheels 24 ft. diameter, with 22 floats, and appears to have had Hall's surface condensers. She appears to have made several voyages across the Atlantic, was afterwards put on the Glasgow and Cork route, and was wrecked in 1847.

In 1819, however, the steam ship "Savannah" made the passage from America to Britain, partly sailing and steaming.

The oldest iron Clyde river steamers still plying are the "Inveraray Castle," built in 1839, and the "Balmoral," formerly the "Lady Brisbane," built in 1842.

The "Fairy Queen" is said to have had an oscillating engine. The well-known steeple engine was invented by Mr David Napier, the "Clyde" being the first steamer to be fitted with one about 1836.

With the iron period of shipbuilding came increased facilities for supplying larger sizes of steam vessels year after year, many of which were launched by the well-known firms on the Clyde.

Like the wooden period, however, the iron period is fast passing away, as many of our river and sea-going steamers are being built of steel which, in its more modern form known as "mild steel," offers itself to be readily fashioned by the shipbuilder and the engineer into the various forms required for ship and boiler work, and from its great strength enables a reduction to be made on the sections formerly required in iron construction.

The following Lists of Early River Steamboats are appended as the names may serve to recall to members particulars which may be of interest to place on record.

LIST of STEAMBOATS plying on the Clyde in 1820, as given in the *Steamboat Companion* for that year.

Nam	Year.	Tonnage	H.P.	Draft. ft.	Draft. in.	Plying to
Comet, .	1812	28	14	5	0	Fort-William.
Argyle, .	1815	78	26	4	0	Inverary.
Britannia, .	1815	109	32	4	6	Campbelton.
Neptune, .	1816	82	20	3	9	Inverary.
Rob Roy, .	1818	87	30	5	9	Belfast.
Robert Bruce,	1819	150	60	8	0	Liverpool.
Inverary Castle,	1819	112	40	4	6	Inverary.
Superb, .	1820	240	72	8	6	Liverpool.
Rapid, .	1820	136	40	7	0	Liverpool & Belfast.
Clyde, .	1813	65	14	3	6	Ports of Clyde.
Glasgow, .	1813	64	14	4	0	,,
Greenock, .	1815	62	10	3	3	,,
Waterloo, .	1816	90	20	3	6	,,
Albion, .	1816	92	20	4	0	,,
Rothesay Castle,	1816	95	30	4	4	,,
Oscar, .	1816	54	12	3	2	,,
Dumbarton,	1820	65	25	3	5	,,
Defiance, .	1817	51	12	3	3	,,
Marquis of Bute,	1818	53	14	3	3	,,
Robert Burns,	1819	66	20	3	6	,,
Port-Glasgow,	1819	84	16	3	6	,,
Fingal, .	1819	67	16	3	9	,,
Postboy, .	1820	65	20	3	0	,,
Samson *(Tug)*,			40			,,

STEAMBOATS calling at GREENOCK in 1836, as given in Fowler's *Commercial Directory for Renfrewshire*, year 1836-37.

To Arrochar.	Tons.
Leven, . .	54
Ayr.	
Nimrod, , .	96
St. Munn, .	56
Belfast.	
Antelope, .	161
Arab, . .	213
Belfast, . .	123
Eclipse, . .	104
Mercury, . .	200
Rapid, . .	239
Toward Castle, .	97
Campbeltown.	
Duke of Lancaster,	90
St. Kiaran, .	128
Campbeltown, Portrush, and Londonderry.	
Foyle, . .	136
Glenalbyn, .	130
Rover, . .	200
St. Collumb, .	140
Dublin.	
Erin, . .	180
Jupiter, . .	288
Dumbarton.	
Leven, . .	74
New Dumbarton,	72
Vale of Leven, .	69

Glasgow.	Tons.
Active (luggage)	59
Alert ,,	60
Commerce ,,	60
Dispatch ,,	58
Favourite ,,	60
Industry ,,	55
Trusty (luggage)	61
James Watt	70
Champion (towing)	60
Gulliver ,,	74
Hercules ,,	74
Samson ,,	49
Gourock, Dunoon, Rothesay, and Glasgow.	
Arran Castle, .	81
Edinburgh Castle,	103
Dunoon Castle,	100
Tarbert Castle,	
Windsor Castle,	90
Helensburgh, Rosneath, and Glasgow.	
Brenda, . .	
Clarence, . .	70
Greenock, .	70
James Oswald, .	68
Royal Tar, .	78
Sultan, . .	68
Waverley, .	55

Inverness, Stornoway, Skye, and Tobermory.	Tons.
Helen M'Gregor,	70
Inverness, .	70
Maid of Morven,	52
Rob Roy, . .	70
Staffa, . .	46
Islay, Staffa, Iona, and Skye.	
Maid of Islay No. 2,	140
Kilmun, Dunoon, and Glasgow.	
Caledonia, .	57
Earl Grey, .	95
Kilmun, . .	102
Largs, Millport, and Ardrossan.	
Express, . .	—
St. Mungo, .	108
Victor, . .	70
Largs, Millport, Ardrossan, Troon, and Ayr.	
Nimrod, . .	96
St. Munn, .	78
Largs and Millport.	
Fairy Queen, .	40
James Denniston,	
Liverpool.	
Ailsa Craig, .	170
City of Glasgow,	183

Steamers calling at Greenock in 1836—continued.

Liverpool—(continued).	Tons.
Clyde,	195
Eagle,	293
Glasgow,	214
John Wood,	180
Liverpool,	200
Manchester,	219
Vulcan,	214
Unicorn,	300

Lochgilphead & Inverary.	Tons.
Dunoon Castle,	100
Tarbert Castle,	
Lochgoilhead.	
Lochgoil,	73

On Loch Lomond.	Tons.
Euphrosyne,	
Rothesay (direct).	
Isle of Bute,	94
Maid of Bute,	92
Stranraer.	
Lochryan,	94

In the after discussion,

The PRESIDENT said, as Mr Millar stated in his introduction, the object of this paper was to put on record, at the present appropriate time, facts relative to the size and form of the early Clyde steamers —facts that, in a very short time, would be lost entirely if not thus collected. It would be noticed that, at the present time, there were doubts regarding the dimensions of some of the early vessels; and, as there were still men among them who had knowledge regarding these vessels, it would be well if they came forward and gave that information, so that it might be placed on record. Facts were also to be found in pamphlets in the possession of some gentlemen connected with the Institution, which, if also sent in, might enable a very interesting record to be made up, and one which, if not obtained now, he was afraid they would never again get. He thought that it would be well to give not only the length and breadth of the vessels, but also their depth and dimensions of the machinery, as a statement of the mere tonnage did not supply sufficient information. If they considered this paper from that point of view, there were many gentlemen who could supply interesting material for forming a pretty complete record of the early condition of ships and shipbuilding on the Clyde.

Mr JAMES GILCHRIST said, in connection with the engines of the "Comet," there was a considerable amount of doubt as to whether

the engine in South Kensington or that in Stobcross Engine Works was the right one. At all events, the two engines referred to were identically the same. If any gentleman would like to see the one at Stobcross, he would be glad to show it.

Mr RALPH MOORE asked if the "Comet" engine had a short slide valve.

Mr MILLAR replied that apparently it had from the drawing given in Professor Rankine's "Manual of the Steam Engine."

Mr WM. HASTIE thought the "Industry" was well worth preserving, as being the oldest steamer now in existence. It might be asked (and be of interest) in connection with this paper—who was the first marine engineer? To learn this we must first ascertain which was the first steamer employed in *trade*. He held it was not the "Comet" in this country, nor the "Clermont" in America, but the "Charlotte Dundas" which plied on the Forth and Clyde Canal at the end of last century towing barges, and did it well, the only drawback being that her paddles injured the banks of canal. The engineer of this steamer, and therefore the first marine engineer working a steamer, was Thomas Tosh. He was employed for many years in the Greenock Foundry (Scott, Sinclair, & Co.'s) and when he became an old man, Mr Robert Sinclair, the locomotive superintendent of the Caledonian Railway Coy., gave him an easy job at their works in Greenock. He died in 1854 aged about 80.

Mr DAVID CAMPBELL would like to say a word about the "Neptune," Capt. Kirkwood, which was chiefly owned by mechanical men whose aim was more to gain experience than the dividends, which could have been realized if the owners had not altered her very much. The "Elizabeth," before the "Neptune," he understood to have been a costly experiment for her shareholders, but he was told by Mr John Robertson, who engined the "Comet" for Henry Bell, that she afforded very useful data to engineers afterwards. When the "Enterprise," engined by Messrs Murdoch, Aitken, & Co., was in the Liverpool trade she made very successful passages. She was fitted with pedestals with deep jaws in order that her crank shafts could be raised to suit her draft of water; they had some trouble

in keeping the points of pedestal jaws together after the shaft was raised. The same engineers engined the "Helen M'Gregor." Mr Murdoch of Port-Glasgow, and Mr Aitken of Whiteinch, are sons of Mr Murdoch and Mr Aitken of the late firm of Murdoch, Aitken, & Co.

Mr JOHN HASTIE said he was the last engineer that had to do with the "Industry" before she was laid up, and could supply some information regarding her. The original engines were taken out and replaced with the engines now on board by Caird & Co. of Greenock; he could not state the date but it was at least 30 years ago. The spur gearing for driving the paddle wheels was retained to the last and was a constant source of trouble on account of the cogs giving way, and spare wheels were always kept in readiness to replace them. She was known in Greenock Harbour as the "Coffee Mill," from the grinding noise occasioned by the cogs. The "Industry" got into collision in the summer of 1862 and met with serious injury to the hull, had one of her paddle boxes carried away, and one of the paddle wheels smashed. The boilers being done it was not considered worth while to repair her. She lay in Greenock Harbour for some time and was afterwards, he understood, presented to the Clyde Trustees.

Mr MAYER said that he had occasion, in 1876, to prepare some historical account of the engineering and shipbuilding on the Clyde and West of Scotland, at the request of the Local Committee for receiving the British Association, and on referring to the summary which he then gave, he found there were one or two points of difference from what had been stated in the paper just read. Mr Millar said that it was about 1836 that David Napier put his first steeple engine into the "Clyde." Now he had stated—"Not the least important improvements which he made were those which terminated in the production of what was long known as the steeple engine, first employed in the year 1832, in the "Clyde," a vessel of 342 tons and 160 H.P., and owned by Messrs G. & J. Burns." He found also, as to the question of iron *versus* wood in shipbuilding, that besides the paper already referred to by Mr Millar, of Mr

Archibald Gilchrist, that he had put down in his historical notes—"So far back as the year 1787, a canal boat, built of iron, was in use in South Staffordshire, and very early in the present century there were other iron-built boats in use for canal traffic in that part of the kingdom. The earliest examples of such structures in Scotland was the 'Vulcan,' built at Faskine, near Airdrie." In order to make the paper complete, he thought that gentlemen who possessed the knowledge, whether members of the Institution or not, should be solicited to transmit it to the Secretary, so that there might be a complete and exact history of the early Clyde steamers put on record. With reference to the lately deceased David Hutcheson, he might remark that that gentleman was present at the launch of the "Comet," so that he formed a connection between the first steamer built on the Clyde and some of the finest specimens of ship architecture ever turned out.

The PRESIDENT was of opinion that the few remarks that had been made were perfectly in the direction in which they required to follow up Mr Millar's paper. They would be glad to get further information about the early types of steamers—historical facts and dimensions of the vessels down to 1830,—so that they might be carefully gone into, and recorded by this Institution. He thought that if they did not get them now it would be difficult to get them again; but he was satisfied that they would get a good deal of information yet, and he thought they might take the remarks of that evening as an earnest of what they might expect at next meeting. They would now adjourn the discussion until next meeting, before which the paper would be in the hands of the members; and he hoped they would get up as much information as possible against the next meeting.

The discussion of this paper was resumed on the 25th January, 1881, when

The SECRETARY stated that he had received communications from Mr George W. Jaffrey, viz., chart and log of first voyage of S.S. "City of Glasgow," and M.S. notes, &c., of early Clyde

steamers. Mr Wm. Kemp had sent a tracing of the oscillating engine of the "Fairy Queen," and he knew that Mr James Gilchrist was prepared to supply much interesting matter to the discussion.

The PRESIDENT said he had no doubt it would take some time before all the particulars in regard to this important subject could be got into proper order. Time would be required to hunt up facts from the places in which they have long been buried away. The tracings of the engines of the "Fairy Queen," furnished by Mr William Kemp, contained substantial and interesting evidence in the history of the oscillating engine; for in the southern part of the island it seemed to be generally believed that the oscillating engine had its birth on the Thames. He thought the fact of it being in that vessel long before any of the engines on the oscillating principle of construction existed elsewhere was just one of the fruits that they might expect to come from this discussion.

Mr JAMES GILCHRIST was satisfied that if they were allowed a little more time there would be many facts gathered regarding this most interesting subject. He had looked into the paper and desired to make a few observations. On page 51 he observed that the vessel "Elizabeth" was stated to have been engined by James Cook of Tradeston. He believed it should have been stated to be John Thomson & Co., Tradeston. At page 53, the engine of the "Industry" was stated as having been made by Mr Thomson of Tradeston, whereas he understood that the probable maker of it was Mr George Dobbie. On page 54, it was said that the "Argyle" was built at Port-Glasgow, it might further have been stated that it was built there by Alexander Martin & Co. Further down the same page the "Dumbarton Castle" and the "Britannia" come in for notice. He found that while the former was designed by Duncan M'Arthur & Co., the venerable father of the late John D. Napier, Mr David Napier, had engined it. He might here state that he was glad to learn, from the late Mr John D. Napier's son, that while looking amongst his father's papers he found an unfinished autobiography of the late Mr David Napier, and he believed he would be able to get that document for publication in the Transactions of

the Institution. In that autobiography it was stated that he had made the engines both of the "Dumbarton Castle," and the "Britannia," although Mr Millar had set down the former to the Messrs M'Arthur and the latter to Mr James Cook. On page 55 there were dates given of the building of various vessels, regarding which he had been consulting with Mr W. Muir, well-known as the oldest marine engineer on the Clyde, and who had been 50 years superintendent of Messrs G. & J. Burns' fleet. He had sent Mr Muir a copy of the paper, and solicited remarks thereon. Mr Muir said that the "Rothesay Castle" was eventually sold to a Liverpool firm and ran to Wales from that port, but was lost on the Cheshire coast. At the foot of the same page, Mr Millar noticed a "Rob Roy" as having been built in 1818. Regarding that vessel Mr Muir said—"I well remember the day that the 'Rob Roy' left for Belfast on her maiden voyage. The river banks were crowded with people seeing her leave and most of them thought and expressed themselves quite satisfied that she would never return." It might be added after the passage on page 56,—"This 'Rob Roy' was transferred to the Calais and Dover service," and "as she was the first steamer in France she was named the 'Henri Quatre.'" Further down that page mention was made of the building of the "Talbot" and the "Ivanhoe," regarding which Mr Muir said that "they were fitted with feathering floats of iron, three of them in the length of the float, and turned on edge as they were coming out of the water. They were wrought with wheel gearing, the paddle rings and paddle shafts being made of cast-iron." On page 57, the "Inverary Castle" and "Post Boy" were brought under notice. Mr Muir informed him that the "Inverary Castle" had a single beam engine, the beam working underneath the cylinder with an oval eye round the air pump. It had a short crosshead for the connecting rod end, and a long crosshead for the cylinder end for attaching side rods. She had two copper flue boilers, one on each side of the engine. This was the only engine on this principle made in Glasgow. The vessel was built by John Wood of Port-Glasgow. The "United Kingdom" was also fitted with copper boilers. The line

of steamers from Glasgow to Liverpool started by Mr D. Napier, as mentioned in the paper, ran from Greenock, not Glasgow, as stated in the paper, only carried passengers in summer. The "Post Boy" was a mere attendant on the other boats. At page 58, "Comet" No. 2 was mentioned. It was built in 1821. Mr Muir was engineer of that steamer. On page 60, the "Royal Sovereign" was said to have been built in 1839, but he was informed that that must be a mistake, for she was running before that date. In paragraph 5 of that same page the "Sirius," built by Messrs Menzies & Son, should be Menzies & Co.; and then on page 66, with reference to Mr Mayer's correction of Mr Millar regarding the "Clyde." He had been speaking with his father (Mr A. Gilchrist) on this point, and he assured him that the "Clyde" must have been sailing early in 1832 (not 1836 as stated in the paper), as the late John M'Gregor, of Tod & M'Gregor, was engineer in that steamer, the last one he had charge of, and he left her and started with Mr Tod at the foot of Carrick Street, Glasgow, as marine engineers in 1832, and their first job was to make engines for the "Helen M'Gregor," which plied to Inverness. She had double crosshead engines and intermediate shaft of cast-iron, the cranks being cast on. Mr Muir in his note gave the following interesting notes:—"The first line of cargo steamers direct from Glasgow to Liverpool was started in 1829 by Messrs G. & J. Burns, their first steamer being the "Glasgow," whose tonnage was 280, and horse power 100. She was built by John Wood and engined by Caird & Co., of Greenock. She had side lever engines with two boilers of iron, and steam pressure of 5 lbs. to the square inch. There was no gauge glass to indicate the height of water, but three gauge or test cocks were put on the end of each boiler. The second vessel for Messrs Burns was the "Ailsa Craig," built in 1829. Her tonnage was 297, the horse power 100. She was fitted with side lever engines made by Duncan M'Arthur, Glasgow. The third vessel, the "Liverpool," was built in 1830; tonnage 330; horse power 150. She had two copper boilers, with direct overhead engines, having side levers for working air pumps; steam pressure 6 lbs. The engines were made by Caird & Co., and

the ship was built by Steele & Co., Greenock. This vessel was built of light draught, to suit the river at that period; and even took the ground at neat tides. On rare occasions she got down or up the river in one tide, but only then on the top of the springs. Before sitting down, he would like to suggest, that this very important discussion should not be closed in a hurry. There were a few very old engineers living who could, and no doubt very willingly would give us some useful information; and he therefore proposed that after hearing all that the gentlemen present had got to say on the matter that the subject be postponed to give time to glean all the possible information bearing upon it. He had handed Mr Millar two tables published by Dr Cleland; the small one in 1816 (see p. 72), of steamers built prior to that year, and the large one of vessels built up to 1828, and published in 1831, which contained valuable information. He had also brought a tracing of the "Comet's" engines, which he had referred to in his remarks at the previous meeting.

The following Table gives the Names, Dimensions, &c., of Steamboats on the Clyde in 1816.

No.	Name.	When Launched.	Length of Keel.	Length of Beam.	Carpenter's Name and Residence.	Size of Engine.	Engine Maker's Name and Residence.
			Feet.	Ft. Ins.			
1	Comet, . .	Jan., 1812	38	11 6	Jn. Wood & Co., Port-Glasgow,	6 horse power	Henry Bell, Glasgow,
2	Elizabeth, .	Nov., 1812	40	12	Jn. Wood & Co., Port-Glasgow,	10 horse power	J. Thomson & Co., Trdstn., Glas.
3	Clyde, . .	Feb., 1813	68	14	Jn. Wood & Co., Port-Glasgow,	10 horse power	John Robertson, Glasgow.
4	Glasgow, .	Sep., 1813	60	15	Jn. Wood & Co., Port-Glasgow,	14 horse power	Henry Bell, Glasgow.
5	Trusty, . .	Feb., 1814	65	16	William Denny, Dumbarton,	10 horse power	George Dobbie, Tradeston, Glas.
6	Princess Charlotte,	Mar., 1814	65	10 6	James Munn, Greenock,	2 engines, ea. 4 h.p.	Bolton, Watt, & Co., Soho.
7	Industry, .	May, 1814	65	16	Fairlie,	10 horse power	George Dobbie, Tradeston, Glas.
8	Prince of Orange,	June, 1814	64	12	James Munn, Greenock,	2 engines, ea. 4 h.p.	Bolton, Watt, & Co., Soho.
9	Argyle 1st, .	June, 1814	72	14 6	A. Martin & Co., Pt.-Glasgow,	14 horse power	Jas. Cook. Tradeston, Glasgow.
10	Margery, .	June, 1814	56	12	William Denny, Dumbarton,	10 horse power	Jas. Cook, Tradeston, Glasgow.
11	Britannia, .	Jan., 1815	80	16 8	John Hunter, Port-Glasgow,	24 horse power	D. M'Arthur & Co., C'mlachie, do.
12	Dumbarton Castle,	Feb., 1815	84	16 8	William Denny, Dumbarton,	30 horse power	D. M'Arthur & Co., C'mlachie, do.
13	Caledonia, .	Apr., 1815	86	15	Jn. Wood & Co., Port-Glasgow,	2 engines, ea. 18 h.p.	Greenhead Foundry Co., do.
14	Greenock, .	May, 1815	80	16 8	William Denny, Dumbarton,	32 horse power	D. M'Arthur & Co., C'mlachie, do.
15	Argyle 2nd, .	July, 1815	72	15	Jn. Wood & Co., Port-Glasgow,	20 horse power	Greenhead Foundry Co., do.
16	Waterloo, .	Jan., 1816	72	16	John Hunter, Port-Glasgow,	20 horse power	James Cook, Tradeston, do.
17	Neptune, .	Feb., 1816	68	15 5	Jn. Wood & Co., Port-Glasgow,	20 horse power	D. M'Arthur & Co , C'mlachie, do,
18	Lord Nelson,	Feb., 1816	71	16	Jn. Wood & Co., Port-Glasgow,	20 horse power	Greenhead Foundry Co., do
19	Albion, .	Mar., 1816	73	16	Jn. Wood & Co., Port-Glasgow,	20 horse power	James Cook, Tradeston, do.
20	Rothesay Castle,	Apr., 1816	76	16 6	William Denny, Dumbarton,	34 horse power	D. M'Arthur & Co., C'mlachie, do.

Mr GEORGE RUSSELL said he quite sympathised with the remarks of Mr Gilchrist on the desirability of giving time for getting more reliable information upon the subject. He had been comparing Mr Millar's paper with some authorities published at the time. In *Cleland's Annals of Glasgow*, published in 1817, there was a considerable number of statistics given regarding some of the vessels mentioned by Mr Millar. The dimensions of the "Comet," as given by Cleland were 38 ft. keel, 11 ft. 6 in. breadth of beam, and 6 horse power. The "Elizabeth" was 40 feet keel. The "Clyde" is given as 68 ft. keel, instead of 72 ft. The "Glasgow," 60 ft. instead of 72 ft. In Cleland's table the six steamers built in 1814 were given in this order, and not in the order of the paper,—"Trusty," "Princess Charlotte," "Industry," "Prince of Orange," "Argyle" No. 1, "Margery." The "Industry," as Mr Gilchrist had told them, was engined by George Dobbie, was 65 feet by 16 feet. The "Princess Charlotte" was built by Mr James Munn; the "Margery" by Archibald Maclauchlan, her length being 56 feet instead of 63 feet. There were five instead of six steamers built in 1815. The first was the "Britannia," and the others followed in this order, — "Dumbarton Castle," "Caledonia," "Greenock," and "Argyle" No. 2. The "Waterloo" was launched in January, 1816, by John Hunter, Port-Glasgow. The "Greenock" was 32 horse power, not 10 as stated in the paper, and engined by Duncan Macarthur & Co. The "Caledonia" was 86 ft. long, and had two engines of 18 horse-power each. The "Dumbarton Castle" was 30 horse power, and was 84 ft. by 16 ft. 8 in. The "Britannia" was 24 horse power, and 16 ft. 8 in. beam. The order in which vessels built in 1816 are given by Cleland was "Waterloo," "Neptune," "Lord Nelson," "Albion," "Rothesay Castle." The "Albion" was 73 ft. by 16 ft It was most important that the facts regarding at least those first 20 vessels should be properly put down, and if it were possible to get the sizes and full particulars accurately it would add greatly to the interest of the paper.

Mr DAVID CAMPBELL said in reference to the "Fairy Queen," he might state that he had sailed in her as a passenger from Gourock.

She had oscillating engines, and he remembered well of the vessel being conveyed along Buchanan Street on wheeled carriages to the river. He had seen the steam-ship "Sirius" at Cronstadt in 1839, and then she was trading between London and St. Petersburg. He believed she was one of the first vessels that crossed the Atlantic.

Mr MILLAR said, with reference to the "Industry" he had taken Mr Robert Cook as his authority for stating that she was engined by Mr Thomson, and stated that in collecting information for the paper he had noticed considerable differences in the descriptions of the vessels and the manner of the construction, and in reference to the "Elizabeth" and some of the other vessels mentioned by the previous speakers, he had also taken Mr Robert Cook as his authority, as he had kindly supplied interesting details from personal knowledge. He might state that in speaking to Mr Jaffrey as to the date of the "Clyde," he thought it must have been nearer 1836 than 1832, and amongst the manuscript notebooks which this gentleman had handed to him he found that the "Royal Sovereign" was built in 1839, the "Royal George" also in 1839, and the "Princess Royal" in 1841. He had been unable to find any record of the builders of the "Comet" No. 2. Mr Gilchrist, however, through Mr Muir, might be able to supply this.

The PRESIDENT said he thought from what they had heard that night that they had got fairly to the beginning of this important subject. It was evident that the dimensions of these vessels must have been taken by the parties at the time in different ways; some would take length of keel and forerake. It was most important to get the length and breadth and depth, the diameter of cylinders, length of stroke, diameter of paddle wheels, draft of water, &c., the builders of the vessels, and makers of the engines, and also the stations on which they were employed and their ultimate career. These facts would form a very important history of early steam vessels, and be of use in future times. He agreed with Mr Gilchrist that they must not be in a hurry with this subject. They ought to postpone it for the purpose of gathering as much information on the subject as possible. He would go further and propose that when

they had got all the information possible from their own members, that every member of the Institution should seek to interest his friends in the matter, and especially to ask any of them who had any connection with firms who had either built or engined any of those vessels, to obtain the desired information. That could be compiled, and he would suggest that it be referred to a committee, so that the whole matter obtained might be considered and prepared in reference to those vessels built down to 1830. If these suggestions were agreed to, he thought they might terminate the discussion for the present, and bring it up at following meetings until it was time to place the information in the hands of a committee who would do the subject justice. It was perfectly evident from the remarks that night that their information must be sifted to make it valuable. He had no doubt that they would be doing an important work if they could put upon record a trustworthy statement in reference to all those early vessels and the people connected with them.

The discussion on this paper was again resumed on 22nd February, 1881.

Mr MAYER handed in a newspaper cutting containing a list of steamers plying on the Clyde in 1832, and including a letter from the late James Smith, Esq., of Jordanhill.

Mr JAMES ROBERTSON said that the late Mr David Elder, jun. had been engaged collecting materials for a history, not so much of the work done by Clyde shipbuilders and engineers; but of the engineers and shipbuilders who constructed the early boats and engines. He had no doubt that Mr Elder had left considerable materials behind him for such a work, and was eminently qualified to carry it to completion. If access could be got to his materials, he had no doubt it would be of great use in the present inquiry. He (Mr Robertson) was manager to Messrs Mitchell & Wallace, the late proprietors of that old centre of engineering, Camlachie Foundry, where David Napier, and afterwards Robert Napier, first built marine engines. There he made his first acquaintance with the

late Mr James R. Napier, with whom he had held frequent conversations about the old engineers on the Clyde, such as the late David Napier and Robert Napier. He thought Mr Thomas Wingate would be able to give a great deal of information regarding the men who took part in the building of the earliest Clyde steamers. The earlier struggles of such men as the Messrs Napier and Elder, well related, would be an interesting story of hard work and difficulty overcome—perhaps as interesting as was the story of the lives of the railway engineers, as related by Mr Smiles.

The PRESIDENT said he could endorse what Mr Robertson had said with regard to the late Mr David Elder, jun., and it was possible that he might be able to find out the materials referred to if still in existence. He would do all in his power to obtain them.

The SECRETARY intimated that he had received letters containing further information on this subject from Mr James Gilchrist and Mr James Cook, and Mr A. Russell, Anderston Foundry, had sent a long list of vessels plying on the Clyde between 1835 and 1845. He had also had a conversation with Mr Walter Neilson, with regard to the engines of the "Fairy Queen," Mr Neilson promising to get what information he could on this subject.

On the Corrosion and Preservation of Iron and Steel.

By Mr CHARLES C. LINDSAY, Assoc. M. Inst. C.E.

(SEE PLATES VI. AND VII.)

Received 24th, and read 25th January, 1881.

THE object of this paper is to describe the effects produced by corrosion on iron and steel under various conditions, to point out the necessity for great improvement in the paint coatings commonly in use for the protection of these metals, and to describe methods employed for arresting and preventing decay.

Part of the paper is compiled from information obtained from chemists and engineers of eminence, part of it gives the result of the author's experience, and part is the result of research over a widely scattered area of literature on the subject,—and it is to be hoped that the bringing together of this experience and scattered information may prove of some use, and that it may elicit an exhaustive discussion; as there can be no doubt that the interchange of opinions and the results of experience, by the members of the various professions which make up this Institution, is the best means of arriving at the accuracy of the data and deductions given, and the value of the preservatives described and in use.

The scope of the paper does not include the corrosion of iron and steel subject to chemical action further than that which results from the constituents commonly found in air, rain water, and the waters of seas and rivers; nor does it include the corrosion of boilers. It is, however, difficult to draw hard and fast lines, as the consideration of the subject must necessarily trench upon the excluded ground to a certain extent.

Importance of the Subject.

It must be apparent to every rational member of the engineering profession that the importance of the subject has been sadly underestimated, considering the immense interests involved. These interests were very small when Pritchard's cast-iron bridge was erected near to Colebrookdale, in 1779; when Boulton and Watt introduced the slide valve and the condenser in the latter end of last century; when Fulton and Bell first plied their steamers in 1807 and 1814; and when, in 1829, Stephenson completed his locomotive, the "Rocket." With these inventions and improvements, however, the interests received a marvellous impulse, a new era was inaugurated in the iron age, the uses of iron were multiplied, and now it is used not only for every conceivable purpose to which wood and stone have been applied, but its introduction, and that of steel, has given rise to new forms to which wood and stone are not applicable. The rapid stride made is confined to a period within the memory of many men now living—certainly a short period in the history of the world,—yet it is almost impossible for man to grasp an idea of the extent to which iron and steel are used, or to estimate the amount in use.

Representing, as iron and steel do, almost infinite wealth, what has been done to protect them from decay? Chemists and engineers have neglected this essential, and it would seem that, in the hurry to produce them, their corrosion has been almost forgotten, and the object sought—the non-corrosive gold which they produced.

It is true that some efforts have been made, by alloys, and otherwise, to make iron non-corrosive, and that preservatives have been announced, from time to time, which have successfully retarded oxidation for a few years, but the best efforts made have fallen far short of making iron and steel as durable as the wood and stone which they have supplanted, and it is only within the past year or two that any marked advance has taken place in this direction.

A very casual observance of our road and railway bridges, and other iron structures, suffices to show that, with but few exceptions,

little attention is being paid to their preservation. The loss of strength each year must be very great, with a proportionate depreciation monetarily.

The most important phase of the question is the consequences of this neglect. Without doubt, the past fifty years will rank as the most remarkable epoch in history as regards the constructive arts, but it is to be feared that some of the legacies left will tarnish its fair fame. Though of wide application, these remarks have an especial reference to wrought-iron structures, as the opinions of some of our eminent engineers show. In the discussion to a philosophical paper, by Mr E. Clark, M. Inst. C.E., on the "Durability of Materials," Dr. Pole stated "that he had considerable doubts as to the durability of wrought-iron bridges owing to their liability to be damaged by rust," and "he thought it a grave question for the profession whether the use of light wrought-iron structures was not being carried too far;" and, in the same discussion, Mr Clark said that "the durability of the Britannia Bridge was entirely due to the great care taken for its preservation." The Americans and Canadians pay great attention to their railway and other bridges, to prevent decay; and in this respect teach us an excellent lesson. It is impossible to contemplate some of our iron structures, and the nature of their construction, without feeling that Nemesis will come some day. Take an example from modern architectural practice—the present system of constructing immense piles of stone buildings on a lower storey consisting almost wholly of cast-iron columns and cast or wrought iron girders. The ironwork is ordinarily of the most inferior description, both in texture and design, and is often without any kind of preservative coating. Nobody has the faintest idea of the progress corrosion is making, because the work is out of sight; and it appears that the collapse of the building is merely a question of time.

Having glanced at the importance which surrounds the subject under consideration, it may be asked what are

The Agents which Determine Corrosion?

Popularly, the belief obtains that iron and steel corrode under all conditions, but it is well known to most engineers that this is not the case. They do not corrode in perfectly dry air, and they are but little affected in moderately dry air, such as exists in many parts of the world. In St. Petersburg and in some parts of Canada, where iron roofs are in general use, the material shows but slight signs of corrosion after many years' exposure.

Zumstein placed a polished iron cross on the summit of Monte Rosa, in the Alps, in August, 1821, and on returning twelve months afterwards found no signs of corrosion, and the iron had merely acquired a bronze-coloured tarnish.

In pure distilled water, below the boiling point, neither iron nor steel give rise to any chemical action.

Till very recently—nine years ago—it was generally believed, even by chemists, that rust consisted merely of the hydrated sesquioxide of iron, and that corrosive action, in the presence of moist air, was as follows:—Oxygen, for which iron has a great affinity, is taken from the air, and forms a first coating of the protoxide (Fe O), containing 56 parts by weight of the metal and 16 parts of oxygen; this protoxide combines still further with the oxygen of the air, and adds twice 16 parts of oxygen in combination with a second 56 parts of the metal, forming a higher oxide called the hydrated sesquioxide ($Fe_2 O_3$) or rust. The uncorroded iron underneath then robs the sesquioxide of part of its oxygen, a new layer of the protoxide is formed, and the outer coating becomes in this way an excellent medium whereby the protoxide extracts the oxygen from the air; and thus layer after layer of rust is formed, which continues till the iron is completely oxidised.

This sequence of the action is believed by most chemists to be correct, but Professor F. Crace Calvert pointed out conclusively, in 1871, that carbonic acid played a very important part in corrosive action, and that rust was not simply sesquioxide of iron.

His analyses of two specimens of iron rust—one taken from the

Conway Bridge, the other obtained at Llangollen—which were, as far as possible, free from contamination, are as follows:—

	Conway Bridge.	Llangollen.
Sesquioxide of Iron, . .	93·094 ...	92·900
Protoxide of Iron, . . .	5·810 ...	6·177
Carbonate of Iron, . . .	0·900 ...	0·617
Silica, ...	0·196 ...	0·121
Ammonia, ...	trace ...	trace
Carbonate of Lime, . . .	— ...	0·295

These results aroused his suspicions as to the true cause of oxidation, and he instituted a series of experiments to determine whether it was due to the direct action of the oxygen of the atmosphere, or to the decomposition of its aqueous vapour; or if the very small quantity of carbonic acid which it contains determines or intensifies the oxidation of metallic iron.

He experimented on perfectly clean blades of steel and iron, and after exposing them for a period of four months to pure oxygen, carbonic acid and ammonia, and traces of moisture, he proved that "*pure and dry oxygen has only feeble action, dry or moist pure carbonic acid has no action, but that moist oxygen containing traces of carbonic acid acts most rapidly on iron, giving rise to protoxide of iron, then to carbonate of the same oxide, and last to a mixture of saline oxide and hydrate of the sesquioxide of iron.*" From this he deduced that "*it is the presence of carbonic acid in the atmosphere, and not its oxygen or its aqueous vapour, which determines the oxidation of iron in common air;*" and that "*carbonic acid promotes oxidation.*"

Rate of Corrosion and Practical Deductions.

The rate at which corrosion proceeds is commanded by the relative position of the structure. If on land it depends upon the hygrometric state of the atmosphere and the presence of acids, and if in water upon its being fresh or salt, pure or impure.

We are indebted to Mr Robert Mallet, F.R.S., M. Inst. C.E., for very complete information on these points based upon systematic

experiments carried out at the request of the British Association between the years 1838 and 1843. For these experiments he obtained authentic specimens of cast-iron, wrought-iron, and steel from the principal makers in the United Kingdom. The specimens of cast-iron were melted in crucibles to avoid contamination, and cast as nearly as possible of the same temperature, into parallelopipeds five inches by one inch thick, and five inches by a quarter of an inch thick respectively, and cooled at the same rate. The whole of the specimens of iron and steel were weighed with the utmost nicety and enclosed in separate cells in kyanized oaken boxes constructed so that the iron used in binding the sides did not enter into the interior, and so that their form gave free access to air and water. Thus encased the specimens were sunk in water which may be taken as typical,

(I.)	In clear sea water at temp.	46 deg. to 58 deg.	Fahr.
(II.)	In foul sea water „	46 deg. to 58 deg.	„
(III.)	In clear sea water „	115 deg.	„
(IV.)	In foul river water „	36 deg. to 61 deg.	„
(V.)	In clear river water „	32 deg. to 68 deg.	„

The result showed that under these conditions clear sea water at 115 deg., which is much exceeded in tropical waters, produced the greatest amount of corrosion, that foul sea water was almost as destructive, and that the least corrosion was produced by clear river water. Other specimens were exposed to the air.

His investigations led him to believe that the great elements of difference in corrosion as regards iron itself are:—1, The degree of homogeneity of substance of the metal and especially of its surface. 2, The degree of density of the metal and state of its crystalline arrangement. 3, The amount of uncombined carbon or suspended graphite contained in the iron. Other eminent experimentalists have agreed with him in these particulars and in the conclusion that, —The more homogeneous, the denser, harder, and closer-grained, and the less graphitic the iron, the smaller is the index of corrosion.

The corrosion of iron and steel is exhibited in one or other, or

some combination of six characteristics states of oxidation varying with the nature of the metal, as follows:—1st, *Uniform;* 2nd, *Uniformly Striated,* in the case of wrought iron and some kinds of steel only; 3rd, *Uniform with plumbago,* or where the latter is seen in patches after the surface has been scraped; 4th, *Local,* where the surface is rusted only in some places; 5th, *Local Pitted,* where the surface is found unequally corroded so as to leave a pitted uneven surface; 6th, *Tubercular,* where the rust has been transformed to points, forming projecting tubercules. These terms were first applied by Mr Mallet, and have been generally adopted.

For practical purposes he deduced that "*from three to four-tenths of an inch in depth of cast-iron, one inch thick, and about sixth-tenths of an inch in depth of wrought-iron will be destroyed in a century in clear sea water.*" Other deductions will be given further on.

The accuracy of these deductions was closely verified by comparison with the effect produced by clear sea water upon the guns taken from the wreck of H.M.S. "Edgar," which after immersion for one hundred and twenty-nine years, were corroded to a depth of $\frac{7}{8}$ of an inch; and, also by comparison with iron from the "Royal George," immersed for forty-eight years, with a corrosion of from one-half to three-fourths of an inch in depth.

Mr Thomas Stevenson gives examples of more rapid decay than those found by Mr Mallet. In his work on Harbours he states, that on the completion of the Bell Rock Lighthouse Mr R. Stevenson directed cast-iron tramways consisting of rails with open gratings between, and supported on standards, to be fixed to the rock, and adds that "many of these gratings which are not constantly immersed are now decayed in different places, cavities having been formed on their upper surfaces fully half an inch deep, thus giving *one inch to the century for castings an inch square;*" and again, one of the bars which was quite free from air holes presented no external appearance of decay but had its specific gravity reduced to 5·63 and its transverse strength reduced from 7409 to 4797 lbs. Another apparently sound specimen was reduced in strength from 4068 lbs. to 2352 lbs., having lost nearly half its strength in about fifty years."

It will be seen from the experience thus gained that in order to judge of the effect of sea water on cast-iron it is necessary to test it, as the weakness may exist without being apparent to the eye.

Mr E. Clark relates a case of very rapid decay in a hundred isolated plates $\frac{1}{4}$ inch thick, intended for, but not used in the construction of the Britannia Bridge. They were at times wet by the spray from the sea and at the end of two years were literally swept away, having been completely changed to rust.

It is well known that immersion in sea water for a long period causes cast-iron to soften and assume the form of graphite, plumbago, or carbonate of iron, and often become so soft that it may be cut with a knife. This change takes place more rapidly in cast-iron with its skin removed than when it remains intact. This is due to the density and hardness of the skin and also to the presence of silica extracted from the sand. In many cases the hardness returns on exposure to the air. The more rapid decay related by Mr Stevenson, when compared with the results found by Mr Mallet, may be partly due to the greater friction caused by the sea water, the experiments by the latter having been conducted in comparatively still water with specimens partially protected by the boxes in which they were placed.

It has been observed that the loss in thickness of iron plates forming the hull of a ship is accelerated by the friction due to the water. Mr E. W. De Russett, M. Inst. C.E., relates that after 14 years' service the P. and O. S.S. "Bengal" had her strakes examined by drilling holes in various places and gauging them. The loss of thickness in the plates was as follows :—

	As built, 1853	After 14 years' service.	Loss.
	inch.	inch.	inch.
Garboard strake, ...	$\frac{14}{16}$	$\frac{14}{16}$	0
Garboard to 4 feet water line, .	$\frac{12}{16}$	$\frac{12}{16}$	0
4 ft. water line to 6 ft. water line,	$\frac{12}{16}$	$\frac{10}{16}$	$\frac{2}{16}$
6 ,, 12 ,,	$\frac{10}{16}$	$\frac{9}{16}$	$\frac{1}{16}$
12 ,, 16 ,,	$\frac{10}{16}$	$\frac{7}{16}$	$\frac{3}{16}$
16 ,, 18 ft. load water line,	$\frac{10}{16}$	$\frac{6}{16}$	$\frac{4}{16}$

The table shows that the greatest loss occurred at the 18 feet load line, where it was $\frac{1}{4}$ of an inch. It also shows that the means used to protect the iron from corrosion were successful.

Many experiments have been made recently to test the relative durability of wrought-iron and modern steel. Mr Sergius Kern, M.E., St. Petersburg, who has given great attention to the matter, placed clean smooth plates of wrought-iron and mild steel in sea water for 30 days. Each piece was 3 inches square by $\frac{1}{8}$ inch thick. The following table gives the corrosion:—

1,	Mild steel,	loss in grains,	22·75
2,	,,	,,	22·34
3,	,,	,,	21·83
4,	,,	,,	21·96
1,	Wrought iron,	,,	25·78
2,	,,	,,	25·54
3,	,,	,,	26·04
4,	,,	,,	27·44

The average loss in the steel was ·087 per cent., that in the iron ·103 per cent.

The analyses of the metals were as follow:—

	Steels.				Irons, average analysis.
	1	2	3	4	
Carbon,	·29	·30	·18	·23	·11
Manganese,	·38	·412	·275	·178	·187
Sulphur,	·01	·010	·012	tr.	·010
Phosphorus,	·005	·008	·010	·032	·004
Silicon,	·015	·011	·010	·021	·008
Copper,	nil	nil	nil	nil	traces

The author is indebted to Mr George S. Packer, chemist to the Steel Company of Scotland, for the following original tests for the comparative corrosion of well-known wrought-iron and Siemen's steel.

The pieces used were, one piece of Lowmoor boiler plate, one piece of "Glasgow Best" wrought-iron, and three pieces of steel manufactured by the Company. Each piece was $1\frac{1}{2}$ inch square and $\frac{5}{16}$ inch thick (except the "Glasgow Best" which was $\frac{1}{4}$ inch.) Each of them were cleaned from scale and presented a smooth surface, so as to test them under precisely similar conditions. They were immersed in clear sea water of 1·025 specific gravity, 8 inches apart, for a period of 15 months, the water being changed when necessary.

The following are the analyses of the metals used:—

	Lowmoor.	Glas. Best.	The Company's Steel.		
	1	2	3	4	5
Carbon, .	·10	·05	·15	·19	·17
Silicon, .	tr.	tr.	·04	·03	·06
Sulphur, .	·002	·04	·05	·06	·06
Copper, .	tr.	·02	tr.	tr.	tr.
Phosphorus, .	·101	·360	·07	·07	·07
Manganese, .	·237	·172	·635	·244	·525
Slag, . .	·553	2·133	nil	nil	nil
Specific Gravity of Metals.					
	7·786	7·615	7·848	7·847	7·753

Corrosion—Loss per cent.

(Calculated on original weight of each piece.)

	Lowmoor.	Glas. Best.	The Company's Steel.		
	1	2	3	4	5
At end of 1 mo.	·107	·091	·115	·114	·121
At end of 15 mo.	·791	·579	·600	·783	·881

The "Glasgow Best" iron exposed a slightly smaller surface than the other specimens, but allowing for this its rate of corrosion is considerably less than the other metals, which may be accounted for by the protection due to the interlaminated slag.

Mr Packer states, that experiments under the same conditions, conducted by a friend, led to the same results; namely, that of a common make of iron showing greater durability than a superior make. The experiments led him to believe that density is an important factor in the rate of corrosion; but he considers that in making steel dense to increase its durability makers would run the risk of producing hard metal.

Mr Packer lays great stress on the removal of scale from specimens and the preparation of a clean surface in order to obtain a fair comparison between the various makes of iron and steel.

Mr B. H. Thwaite has given considerable attention to the corrosion of metals, and has deduced the following average co-efficients of corrosion of iron and steel under various conditions for 12 months from experiments by Mr Mallet, Professor Calvert, and others.

Co-efficients of Corrosion of Iron and Steel on 1 square inch of surface in 12 months.

	Foul Sea Water.	Clear Sea Water.	Foul River Water.	Clear River Water and Pure Atmospheric Air.	Atmosph. Air of City or Manufacturing Districts or Sea Air.
	grains.	grains.	grains.	grains.	grains.
Cast-iron, .	3·50	3·386	2·034	·604	2·637
Wrought-iron,	10·45	5·855	7·680	·665	6·690
Steel, . .	10·370	5·175	6·045	·675	6·675
Cast-iron with skin removed by planing.					
	12·275	4·738	3·884	0·584	4·763

By using this table the life of iron and steel may be calculated approximately by dividing the weight of the cubical section (one inch in length) of the metal in grains by the co-efficient of corrosion multiplied by the perimeter of the section in inches, which will be equal to the years of existence of the metal. The life of the structure or machine will, of course, terminate when the breaking stress of the metal is reached and imposed upon the reduced section or sections of the metal.

Investigations by Mr Daniel Adamson, a high authority, upon specimens of iron and steel immersed for 17 days in dilute sulphuric acid led to the following results: common iron lost 79·0 per cent.; boiler plate, 46·4 per cent.; best best boiler plate, 34·7 per cent.; medium hard Bessemer steel, 13·0 per cent.; and soft Bessemer steel, 4·8 per cent. These results may be taken as equivalent to long exposure to the air or immersion in water.

Very rapid corrosion takes place where iron or steel is subject to the action of "bilge" water—so much so, that rivet heads are found to be completely destroyed in a short time. Mr De Russett states that in the P. and O.S.S. "Ripon," after fourteen years' service, the exposed plates—originally $\frac{11}{16}$ inch thick—were worn to $\frac{3}{16}$ inch, and the landing edge of the inside strake was worn to a knife edge.

It may be here mentioned that a remedy for the corrosive action of bilge water—beyond that afforded by the cement ordinarily used—may be found by using lime, or any caustic alkali. Berzelius first published the fact that "*caustic alkalies prevent oxidation of iron,*" and it was subsequently verified, by experiment, by Mr Mallet, Professor Calvert, and others, and practically tested by Mr James Young of Kelly, in his yacht, with excellent results. Sir William Thomson effectively prevents corrosion in his deep sea sounding machine by immersing it in lime water.

It will be observed from the results here recorded that the corrosive indices of wrought-iron and steel are nearly the same, but slightly in favour of steel. This result was verified by the Admiralty through experiments made upon the hull of the "Camel," and it was determined to use steel, on account of its comparative light-

ness, in preference to iron in constructing the ships of the Royal Navy.

The contact of iron with metals of electrical polarity presents another phase in corrosive action. Mr Mallet, and others, have investigated the matter with the following results, collected by Mr B. H. Thwaite :—

CORROSION PER SQUARE INCH OF SURFACE IN 12 MONTHS.

						Grains.
Cast iron in contact with brass, in sea water of average foulness,						10·175
,,	,,	copper,	,,	,,	,,	10·685
,,	,,	gun metal,	,,	,,	,,	18·630
Wrought-iron	,,	brass,	,,	,,	,,	14·820
,,	,,	copper,	,,	,,	,,	21·395
,,	,,	gun metal,	,,	,,	,,	24·195

These results show the necessity for making allowance in the thickness of metal where brass, &c., necessarily form part of a submerged structure. For example, journals under water, rollers, chain boxes, &c., in dock gates.

It will be seen from the foregoing Tables that the corrosion of cast iron alone, in foul sea water, is to the corrosion of that metal with brass, with copper and with gun metal in the proportion of 3·5 to 10·175, 3·5 to 10·685, and 3·5 to 18·63 respectively; and that of wrought iron with the same metals, 10·45 to 14·82, 10·45 to 21·395, and 10·45 to 24·195 respectively. It has also been found that wrought iron in contact with cast iron, and cast iron in contact with cast iron of varying density, give rise to corrosion. The former may be seen where the holding-down bolts of marine engine beds come in contact with the cast iron of the bed.

Certain kinds of wood in contact with iron promote oxidation, whilst others are neutral. Among the first, oak and all timbers which contain tannic or gallic acid hold a prominent place, whilst teak is neutral, or nearly so.

Another source of oxidation is to be found in some of the preservatives used for timber—kyanizing, for example.

Iron-sheathed submarine cables, not protected by coatings. when resting on substances of electrical polarity, such as sulphur beds in the bed of the sea, are rapidly corroded. Principal Jamieson, late Electrician abroad to the Eastern Telegraph Company, puts down the average life of such a cable of 10 wires, No. 6, B.W.G., at fifteen years.

Many more interesting results collected in the preparation of this paper might be stated; but that it is necessary to confine the paper within due limits, and it is now proposed to describe.

Methods Employed for Arresting and Preventing Decay.

The consideration of the effect of corrosion in constructional work in iron and steel should commence with the design. In designing castings with "ribs" and "feathers," it is necessary to make contiguous parts as nearly as possible of the same thickness. This precaution is not necessary merely because small members would offer less material for oxidation than thicker ones, but by reason of the proportional increase of corrosion due to the smaller size.

The experience gained by the use of cast-iron pipes, for water supply, and of cast-iron cylinders for bridges and piers, point to the use of castings in "dry sand and loam," in preference to castings in "green sand," for durability. Closeness of grain is also requisite, and this may be obtained by a judicious mixture of several high-class brands and good foundry scrap. Hematite pig iron adds considerably to the durability.

The fusibility of iron, at the time of casting, is a very important point. Iron with a sluggish flow should be avoided, and the metal should fill the mould, show sharp lines, and be free of "cold shuts" and "scab."

All castings should be cooled in the sand slowly, so as to ensure homogeneous metal; for it has been shown that iron of varying density gives rise to electrical action, and consequent loss. The equalizing of contiguous parts, before referred to, considerably assists the formation of homogeneous metal, as inequality gives rise to unequal cooling. The contact of metals, before referred to, is also

to be observed, so as to prevent loss by electro-chemical action when possible.

These are some of the main points to be observed in designing and specifying work to secure durability; others might be mentioned, but we now turn to the consideration of preservative coatings in use.

The practical methods now in use for the preservation of iron and steel are divisible into three classes, viz. :—

1.—By coating with paints and varnishes.
2.—By coating with metals, such as tin and zinc, called tinning and galvanizing respectively.
3.—By coating with magnetic oxide films

Other methods have been proposed and used, but they have not been widely applied or proved effective. One method received some attention. It consisted in coating iron, while hot, with silica (coloured at pleasure) in the fused state. Another method applied to the immersed portions of iron and steel structures, consists in placing zinc plates in metallic contact, so as to give rise to electrolytic action, iron and steel being electro-negative to zinc. Sir H. Davy, and subsequently Professor E. Davy, and Mr Mallet, experimented upon this method, and Mr Mortimer Evans, C.E., has tested it practically at Brodick Pier with, he reports, favourable results. Mr Mallet states, in effect, in his Report to the British Association in 1840, as the result of his experiments, that cast iron, wrought iron, and steel, when immersed in water in voltaic contact with zinc, have their oxidation retarded but not prevented.

Gutta-percha—the prepared sap of a tree called by the same name —which cannot be included under the three classes of coatings given—has highly protective qualities. Under water it imparts a very long life to iron or steel wire coated with it, and is, in consequence, much used as a coating for telegraph wires exposed to damp or immersed in water.

1.—Coating with Paints and Varnishes.

Painting—as a means of preventing corrosion—has had, up to the present time, a more extensive application than any other method. The paints used for that purpose form a large part of a gigantic industry. Without exaggeration, it may be stated that that industry is in a very unsatisfactory state, and that the adulteration practised in it is perhaps on as grand a scale as in any other trade. It is doubtful as to whether the manufacturer, the painter, or the final purchaser is most to blame. One thing is certain, that pure ingredients cannot be produced below a certain price, and it is equally certain that the purest painting materials can be obtained if an equivalent price be given.

The matter has occupied the attention of the author for some years past, but was brought prominently before him about a year ago, in the course of business.

Tenders for painting three large iron bridges were requested from well-known painters, under a specification stipulating that the work was to be done with the "best materials," and the ingredients of the paints were to be of the "purest and best quality," and that "samples of all the ingredients proposed to be used in painting" were to be furnished for the purpose of analysis. Samples from four of the painters that tendered were analysed by Mr. R. R. Tatlock, F.R.S.E., F.C.S., City Analyst, with the following results:—

ANALYSES OF GREEN AND BROWN PAINTS.

	1	2	3	4	5	6	7	8	9	10	11	12
	Green.	Green.	Green.	Dark Green.	Bronze Green.	Bronze Colour.	Metallic Brown.	Bronze Brown.	Bronze Colr. dry.	Brown Bronze.	Light Brown.	Dark Brown.
Sulphate of Baryta,	49·00	24·25	63·25	51·75	44·73	55·33	32·95	58·76	*8·00	58·08	44·01	14·43
Carbonate of Lime,	28·50	26·50	17·00	23·75	11·66	20·40	11·43	21·55	nil	15·36	1·87	13·96
Chrome Yellow,	3·00	7·00	1·29	2·40	2·48	4·06	nil	nil	nil	5·30	nil	nil
Prussian Blue,	·95	·46	·46	·35	·28	·48	nil	nil	nil	1·02	nil	nil
Oxide of Iron,	2·30	9·75	2·00	1·25	9·89	2·22	39·29	3·81	92·00	3·80	21·96	54·21
Red Lead,	nil	nil	nil	nil	nil	nil	nil	trace	nil	nil	nil	nil
Oil,	16·25	32·04	16·00	20·50	30·96	17·53	16·33	15·88	nil	16·44	32·16	17·40
	100	100	100	100	100	100	100	100	100	100	100	100
Foreign matter, per cent.	77·50	50·75	80·25	75·50	56·39	75·73	44·38	80·31	8·00	73·44	45·88	28·39

* silica.

Excepting one sample (No. 9) the foreign matter ranged from 28·39 to 80·31 per cent.

It will be observed that the foreign matter consisted of sulphate of baryta and carbonate of lime, being the "bases" used. The sulphate of baryta is of itself almost unalterable, being one of the most inert substances in nature. The objections to its use in paints of the constitution stated, or in the form in which it is supplied to the trade as a "base" for paints, is that it exposes and separates the particles of oil and colour so that oxidation is rapidly promoted. The carbonate of lime has a most injurious effect upon paints, because it is easily dissolved by the acids contained in rain water. When mixed with sulphate of baryta to form a "base," its solution by acids in rain water, &c., isolates the inert sulphate which soon falls off. The residuum is like a sponge and is a good medium whereby the oxidation of the metal underneath is speedily effected.

These paints may be taken as an example of the paints used when "quality" merely is specified. The securing of a good paint with the desired properties is best accomplished by specifying all the ingredients, analysing samples submitted before the tender is accepted, and further by analysing samples from the paint pots during the progress of contract work.

The primary requisites in a paint for the prevention of oxidation are, that the ingredients used should have no chemical action with one another, that it should adhere strongly to the surface, form a uniform elastic, and impervious coating, and be unaffected by the air and fumes arising from industries.

Paints are ordinarily composed of a "base," oil, colouring matter, and at times a drier. The "base" or solid matter should possess "body" and "covering power," in other words a thin coat of it should be opaque. It should also be unaffected by oxygen, sulphuretted hydrogen, and weak acids.

Practically the only oil used is linseed oil, which is admirably adapted as a medium whereby the base and colouring matter are applied. It should be pure, well boiled, viscid, present a clear amber colour, and dry as a coating of itself in 15 or 16 hours. The specific gravity of a good oil easily obtained in the market is

about 93·975 with water at 100. Resin and the gum of some plants are sometimes used instead of oil.

The colouring matter is regulated by taste, but it should not give rise to any chemical action.

As regards "driers"—turpentine has a good reputation, which it deserves when pure. Litharge, a preparation of lead, should be avoided. Excellent innocuous driers are to be found in sulphate of manganese, and in the borate of manganese mixed with oxide of zinc—the latter is, however, expensive.

All the paints used for coating iron and steel may be classed as follows:—1. Lead Paints. 2. Zinc Paints. 3. Iron-Oxide Paints. 4. Silicate Paints. 5. Resinous and Bituminous Paints.

1. *Lead Paints.*—This term is applied to all paints having red and white lead as a "base," or when these leads are used by themselves as colours.

For many years *red lead* was considered by most engineers, and is still considered by many, to possess the quality of preserving iron; indeed, it was part of the creed of the engineer of bygone days to believe in its preservative qualities. The light of chemical science and experience is fast dispelling this delusion, and red lead as a preservative, will soon, it is hoped, be a thing of the past, for the following reasons:—It is a deutoxide of lead—the protoxide and the binoxide—the former is easily dissolved by rain water, which contains carbonic and sulphurous acid, especially in and about large towns. It enters into chemical action with oil, forming, it is believed, oleate of lead. Where salt is present, as in salt water, the lead is reduced to the metallic condition, giving rise, in the presence of rain water, to electro-lytic action, and consequent loss, iron being electro-positive to lead. The last objection here urged against it—not the least—is its injurious effect upon the human system, causing "lead colic," which often proves fatal and invariably leaves an impaired constitution. Its retention is chiefly due to its being easily worked, and its excellent "body" and "covering power."

White lead presents the perfection of "body" and "covering power," and its saponification or oil mixing quality is of the highest

order. It forms the "base" of most of the paints used. The observation made with regard to the reverence with which red lead has been held, applies with greater force to white lead, as far as painters are concerned. The advantages gained by its use already stated are outweighed by its disadvantages, which are as follows:— It is discoloured by sulphuretted hydrogen which exists in the atmosphere, and this discolouration is determined by the amount of gas present, the intensity varying from a dirty brown to a black. It combines with linseed oil with such force that if the latter be in excess it becomes black. It has a chemical action upon iron. Like red lead it gives rise to "lead colic."

As a general rule the objections stated are applicable to all paints into which any form of lead enters. In a short time they are so altered that their protective qualities are neutralized. Mr Mallet found that the order of protective power of white lead was (10), with coal tar at (4), and asphaltum varnish, as the highest, at (1).

2. *Zinc Paints.*—Owing to the disadvantages attending the use of lead paints, paints having for their base an oxide of zinc—commonly called zinc white—are coming into deserved favour. Zinc white is prepared in various somewhat similar methods from zinc, an ore of zinc, or blende. They are subjected to heat in open retorts in a powerful draught, and afterwards in a close furnace having apparatus for condensing the powdered oxide formed. It mixes well with oil, does not change the colours with which it is mixed, is not darkened by sulphuretted hydrogen, or animal substances. Some "makes" of zinc white possess good "body" and "covering power," though not so good as white lead in these respects. This, however, may be remedied by an additional coat, the cost being much in favour of zinc white. It is not injurious to the system unless used with extreme carelessness, and even then it is scarcely poisonous. On account of its harmlessness and durability, painters are in the habit of finishing inside work with paints based in zinc white.

Substitute for White Lead.—Zinc white is not a perfect substitute for white lead. On the authority of Mr Tatlock the latter is rivalled by a "white" in the market. It is produced by the double

decomposition of sulphide of barium and sulphide of zinc, and the subsequent calcination, chilling in cold water, and sifting of the resulting compound (sulphate of zinc and sulphide of barium). The double decomposition is shown in chemical symbols thus:—

$$Ba.\ S. + Zn.\ SO_4 = Zn.\ S. + Ba.\ SO_4.$$

This white has better "body" and "covering power" than white lead. It mixes with colours without chemical action, is not affected by acids and gases, is not injurious to the health, and possesses all the properties to be desired as a base for preservative paints. The contrast shown by the use of this "white" side by side with white lead may be seen on a bridge over the Clyde near Bothwell. Part of the bridge was painted with one and part with the other, a few years ago, with the result that the part coated with white lead is blackened and impaired, while the other white is fresh and intact.

3. *Iron-Oxide Paints.*—A very excellent substitute for red lead is to be found in artificial red oxide of iron. It is prepared by calcining sulphate of iron (copperas) on iron plates until the water in combination is evaporated and it becomes white. It is then pulverized and submitted to a red heat to expel the acids. The residue is then washed, dried, ground, and sifted. An oxide of the finest quality is obtained by levigation and subsequent calcination. Its salient properties are, a bright durable colour, the highest power of resisting the action of heat, acids, and gases, excellent "body" and "covering power," cheapness, and complete harmlessness, so far as the health and system are concerned.

Native oxide of iron forms the base of an excellent class of paints. The base—a protoxide or peroxide—is found deposited in various parts of the world, notably at Torbay in Devonshire. As much as 85 per cent. of pure oxide of iron is found in some deposits. The process of manufacture entails a great many operations, such as washing, grinding, calcining, sifting, &c., the result being a powder of the fineness of wheaten flour which is passed into pugging mills and mixed with linseed oil, and afterwards through other grinding mills. The paints produced have pleasant, subdued tints.

Artificial and native oxide of iron paints of the best "makes" are

admirably adapted for coating and protecting iron and steel subject to heat, and to immersion in water, whether fresh or salt, pure or impure. Of no other paints can it be said absolutely, that, with them oxidation has done its worst and can go no further.

4. *Silicate Paints.*—The best class of these paints have for their constituents chemically combined sulphate of barium and sulphuret of zinc, to which is added natural silica in a fine state of comminution, the colouring matter (non-poisonous), and the best linseed oil.

In some inferior makes other ingredients are used, including finely ground "slag" instead of natural silica. It is claimed that the silica introduced gives a hard protective coating somewhat akin to enamelling.

A good silicate paint will resist the action of salt water, acids, and sulphurous fumes. It will cost less than white lead paint, and about the same as an iron oxide paint, having good "body," and better covering power than either of them.

5. *Resinous and Bituminous Paints.*—The bases used for resinous paints is resin, or common rosin, from trees of the fir species, and the gummy exudation from certain plants, dissolved in turpentine or spirit. These bases can be coloured as desired.

The gum or resin from the euphorbia plant, a native of Natal, has recently been brought into use as a base owing to its protective qualities. Sir A. Clark, C.B., submitted it to a severe test in the foul waters of one of the basins at Chatham Dockyard, and found, after two years' immersion, that there were no signs of corrosion or fouling on the wrought-iron plates protected by it.

Copal varnish affords a highly protective coating for iron and steel. It consists of resin which exudes from certain trees in the East and West Indies and Africa, with essence of turpentine, in which it is dissolved and prepared for use. The East Indian copal is the best. Mr Mallet gave it the second highest order of protective power.

Common coal tar is the simplest form of bituminous paint. Its protective qualities are of a very high order, and, but for its unsightly appearance, it would have a more extended use. Many

good judges assert that no better covering could be put on ships, bottoms in tropical seas and rivers. When most paints crack and flake off with heat, tar is found to reassume its viscid condition and flow over parts of the surface which have given way,

Prepared natural asphaltum and asphaltum varnish are also forms of bituminous paints. Mr Mallet found that asphaltum varnish had the highest order of protective power, while that of common tar applied hot was 4, with white lead at 10.

One of the widest and most effective applications of bituminous paints for the protection of iron is to gas and water pipes, invented by Dr R. A. Smith in 1848. The method was first put into practice by Mr F. Bateman, M. Inst. C.E., in Manchester, and shortly afterwards introduced to Scotland by the Phœnix Iron Co. The ingredients used in preparing this composition are varied by founders and others. As used by that company it is simple and effective, and consists solely of tar pitch or coal tar from which the volatile oils have been distilled, and a heavy oil distilled from natural bitumen. In preparing the composition for use, the pitch is melted in a circular tank heated round the sides, and of a size suited to the pipes to be coated When melted, the oil is poured in until the mixture has attained a proper fluidity for coating the pipes, which are dipped vertically into it. The proper degree of fluidity, and its maintenance at a temperature of 400 degs. Fahr. under the cooling action of the atmosphere, cold pipes, and other causes, are best known to experienced men. The pipes, which should be free of sand, dirt, and rust, are dipped cold, and allowed to remain in the composition for a time varying with the thickness of the pipes—from a quarter to half-an hour. The pipes should attain a temperature of about 300 degs. Fahr., in order to allow the composition to enter the pores of the metal and form a permanent varnish-like coating.

The following interesting communication from the inventor to the author explains his views with respect to recent practice and, in some cases, mal-practice:—"The pipe coating which has for thirty years been called by my name depends more on the method adopted and the care used than the materials. It has been employed

with fair results only for cast iron. The iron must be cleaned, the pipe must be heated, and the coating material must be allowed to remain in a melted state at least some minutes, perhaps fifteen, so that contact may be complete. The substance used is pitch from the distillation of coal tar. In order to render it more fluid, a little oil is from time to time added. I admired the use of boiled linseed oil, but it has been found that coal oils answer the purpose well. Two modes of heating have been adopted; the first, that of placing the pipes in a stove and then in the pitch. This saves the time during which the pitch receiver is used. The other is by dipping the cold pipes into the pitch, and keeping them there until warm. This operation may be completed in twenty minutes, or so. There seems to be less trouble in connection with this plan, but it depends much on the speed with which the pipes are dipt. If the melted pitch is too much cooled it may be necessary to wait till it becomes sufficiently fluid again. The temperature must not be under 400 degs. Fahr., according to my early experience; but many people have got beyond me in experience, as I have had nothing to do with the matter for many years, in any way, except answering letters concerning it. Until two or three years ago I did not even know the name of the people who used it and sold the materials, and I seemed, to a certain extent, responsible for that which was entirely outside of my knowledge. The plan is not so good as we must desire. It answers well under certain circumstances, especially if the pipes are too much exposed to drying and wetting. Mr Napier Smith, of Glasgow, has been making trials, and, so far as I have tested with cast-iron, his coating has stood better than mine. I suppose he will take a patent for the addition made. I have not received permission to explain it, and I do not know that I understand it. I have not tried it for sheet iron, for which mine is unfitted."

Mr N. Smith has since stated that his improvement—which he has protected—consists in dipping the castings in lime water to remove all traces of oxidizing matter before they are coated with Dr Smith's composition.

From experience gained by engineers, it may be stated that the composition, when properly applied, affords complete protection to pipes for about 20 years. Its use is not confined to pipes, but is used for coating submerged and other ironwork with advantage.

For the protection of submarine cables with galvanized iron wire sheathing, Clark's compound smeared below and above a coating of two layers of hemp, is almost exclusively used. It is composed of:—

65 parts, by weight, of mineral pitch.
30 „ „ silica.
5 „ „ tar.

Principal Jamieson puts down 10 years as the additional life of a cable due to this coating, or 25 years of a total life.

Colours.—As the colouring matter used for paints in many cases gives rise to chemical action, and assists in destroying their protective character, it may be well to give a note of some useful innocuous colours. Two good whites have already been described.

Yellow.—All native ochres, consisting of silica and alumina, coloured with oxides of iron or oxides of manganese, or both. Raw Sienna, a native pigment in the form of an iron ore.

Red.—Oxides of iron, artificial and native. Vermillion — a bisulphide of mercury.

Blue.—Native ultramarine, a compound of silicate of alumina and silicate of soda with sulphide of sodium; much used in painting locomotives.

Purple.—Red oxide of iron tinted with marine blue.

Green.—Chrome green—a sesquoxide of chromium. Terre verte, a silicate of protoxide of iron, with water potassa and magnesium—a native mineral.

Brown.—Raw and burnt umber—an iron ore, with manganese. French brown, from the pyrites cinders of the Tharsis and other mines; consisting chiefly of peroxide of iron, red oxide of iron, tinted with lampblack.

Black.—Bone black, from burnt bones. Lampblack (carbon), the soot of burnt fat, resins, and turpentine.

As a general rule, a mixture of one colour with another produces a fugitive colour. There are, however, exceptions, some of which have been mentioned.

THE APPLICATION OF PAINTS AND VARNISHES.—This section may be fitly closed by a description of what experience teaches us to be the best methods of preparing iron and steel surfaces for protective paints, and their application.

In the case of cast-iron, castings should, immediately on being removed from the mould, and while warm, be cleaned and "dressed," and then receive a coat of, or be dipped in, hot boiled linseed oil. Pipes or castings which are to be coated with Dr Smith's composition, need not be thus treated. Exception may also be made in the case of castings for machinery, on account of the difficulty of working with tools on an oiled surface, and again considering that such castings, forming part of machines, will be under the eye of a tender. In this way some judicious exceptions might be made; but the line should be drawn hard and fast at this class of work, and no exception made in bridge, pier, or other constructional work which cannot receive constant attention. It is argued that the application of oil as described is the best method of preventing the formation of rust, and the oil forms an excellent groundwork for paint. Before leaving the workshop the casting should receive a "priming" or first coat of pure red oxide of iron paint, and after erection two coats of one or other of the protective paints described, finishing with a coat of copal varnish.

In the case of wrought iron and steel, the most effective method of preparing and coating them would be to remove the outer skin of unstable magnetic oxide and incipient rust, heat the parts to a temperature of about 450° Fahr., dip them in a bath of hot linseed oil, and then give them a "priming" coat of red oxide of iron paint, after manipulation in the workshop and before leaving it. The oxide may be removed by dipping the parts in dilute acid and afterwards washing all traces of the acid away. When erected the work should be coated as described for cast-iron work.

The non-corrosion and life of the work depend upon the due maintenance of the coating, and it is necessary to employ men specially to maintain it intact on railway and other viaducts, as practised in America, Canada, and elsewhere.

2.—Coating with Metals.

There are but two kinds of metal coatings which are of practical importance to the engineer—viz., galvanizing and tinning. Galvanized, or properly, zinked iron, was first proposed by Madame Leroi de Jancort in 1791, but it was not till about 30 years ago that it took an important part in constructional work. It consists of iron coated with zinc by the following process. The iron is dipped in a pickle of dilute acid, so as to remove the magnetic oxide scale from wrought-iron and foreign matter from cast-iron, and thoroughly washed, so as to present a perfectly clean surface, and then immersed in a bath of molten zinc. To produce a regular thin coating on plates, they are passed through rollers while in the bath.

The finest and most durable quality of galvanized iron is obtained by tinning it before being dipped in the zinc bath.

Zinc is electro-positive to iron, and, strange to say, is more rapidly oxidized than the iron which it protects. Differing from the latter, however, it combines with an equivalent of oxygen, and the action stops. The oxide formed is insoluble, hence its protective character. If, however, carbon or soot is deposited upon the zinc coating, the addition of sulphuric and other acids in rain water transforms the plate into a series of galvanic batteries, the zinc becomes dissolved by the voltaic action, and the iron is laid bare at various parts, after which it is believed that corrosion proceeds more rapidly than if the iron was not coated. For these cogent reasons, galvanized iron is not suited for roofing in manufacturing districts and large towns Where the atmosphere is clear and pure it is very durable. Latterly galvanizing has been applied to steel. Trials with torpedo boats have proved that it withstands the friction produced by rapid motion better than any other coating tried for that purpose. Opinions vary as to the durability of galvanized iron in

hot climates, such as that of the Brazils and of Ceylon. Galvanizing adds about 5 years to the life of a submarine cable.

Tinning is not extensively used in engineering or structural work, but holds a high place in the protection of domestic utensils. Tin plate is formed of specially prepared thin charcoal iron plates covered with tin. The plates are dipped in molten tin after being cleaned with dilute acid, followed by washing with bran water. After being coated they are placed in peasemeal and cleaned. The process causes the tin to penetrate the iron completely, and gives it a white colour. Tinplate withstands the action of the acids found in rain water, immersion in water, and exposure to the air very well. Like zinc, it forms with oxygen an oxide which protects the plate. Many Continental towns are roofed with tinplate, to which they owe their brilliant appearance in sunshine.

3.—Coating with Magnetic Oxide Films.

Protection from oxidation, apparently of a permanent character, is secured by changing the outer skin of the metal into the black magnetic oxide of iron.

The credit of the first introduction of this method—in 1876—is due to Professor Barff, who made known his invention to the public through the Society of Arts in 1877. In the same year (1877), the Messrs G. & A. P. Bower invented a process—differing from that of Professor Barff's—by which the magnetic oxide film is also formed.

It has often been remarked that Nature almost invariably suggests a means by which her own ravages may be counteracted; and we have but to look to the grains of magnetic iron which have been exposed, alternately wet and dry, on the sea-shore of Taranaki, New Zealand, Arran, Bute, and elsewhere for ages, without the slightest sign of rusting, to apply the remark to the present case. The same imperishable oxide is found at Marbella in Spain, in Carolina, and elsewhere, and turned to practical use by converting it by direct processes into wrought iron and steel.

The application of the oxide for protective purposes has been often foreshadowed. It is well known that the scale on iron and steel

plates—a magnetic oxide—resists oxidation; and Dr Percy, the metallurgist, has pointed out that the iron plates made in Russia, and used for roofing there and elsewhere, owes its remarkable non-corrosive properties to a comparatively stable coating of the oxide formed during their manufacture and preparation for use, the oxide being fixed by steam from green wood placed in the heating furnace. Again, Mr Perkins has found that the iron which has been in contact with his high pressure steam is protected from oxidation, although he was not aware of the cause until recently. And again, Professor Tyndall stated many years ago that metals might be varnished and protected by a powerful gas. These facts, however, do not detract from the high merit of having applied scientific knowledge to so useful a purpose as the preservation of the most useful of the metals.

The Barff Process.—This process consists in submitting articles of iron and steel in a muffle to heat from an ordinary fire until they have attained a temperature which will decompose steam, being a red heat of about 600 deg. Fahr., and then injecting superheated steam at a temperature of about 1100 deg. Fahr. for from 4 to 6 hours. The combined action of the heat and steam transforms the "skin" of the articles into a permanent film of the black magnetic oxide, the thickness of which depends upon the length of time the surfaces are exposed to the steam. It may be mentioned that the formation of this black oxide is formed in an experiment common to every chemical lecture-room—that of generating hydrogen by passing steam through red-hot iron filings placed in a gun barrel.

The latest form of apparatus used for this process is shown on Plate VI. (Figs. 1, 2, 3, 4, 5, and 6.) It consists of a wrought-iron muffle (A), in which the articles to be coated are placed, a furnace (D) for heating the muffle, a heater (J) for superheating steam generated in an ordinary boiler, which is connected to the muffle by a pipe (L), and a furnace (M) for heating the superheater. The other relative parts are given in the reference on the sheet.

Before submitting rusted articles to the process, they are cleaned in the ordinary way with a dilute acid, and light ones like gutter spouts are separated from thick ones. Again, cast-iron articles are

separated from those of wrought-iron and steel, as the former are better coated by steam at a temperature of about 1500 deg. Fahr., while the latter do not require a temperature higher than 900 deg. to form the protective film.

The articles coated by this process (a number of which are before you) present a handsome black appearance. A cast-iron bracket and a wrought-iron rod, tested by Mr R. R. Tatlock, City Analyst, in dilute sulphuric acid, gave highly satisfactory results. The bracket, weighing 3520 grs. (½-lb. nearly) was immersed in water, with 1 per cent. of strong sulphuric acid, for 2 hours, and afterwards washed and dried in the air. On weighing, it was found that but ·14 grain, or ·0040 per cent. of metallic iron, was dissolved, without any sign of rust. The rod weighed 1580 grains (¼-lb. nearly), and on being submitted to the same test, was found to have lost but ·056 grain, or ·0035 per cent. of iron (dissolved), without any signs of rusting. Uncoated iron would have been completely covered with rust by this test. Sir Joseph Whitworth and others have tested metal treated by this process by pressure, with very satisfactory results. It is found that wire coated in this way is rendered too brittle for bending. In applying it to rivetted work it is found to tighten the rivets, and protect the whole from oxidation. The articles submitted which have been treated by this process, by Messrs Dewrance & Co., London, consist of castings of various kinds, wrought-iron gas and water piping, handles of doors, hinges, chains, screw nails, cooking utensils, &c., which show that it has been very widely applied.

The Bower Process. — By this process the protective film of magnetic oxide is formed by first submitting articles of iron and steel to heat, and the action of the products of combustion of coal, largely mixed with air, and then to the carbonic oxide gas, called respectively oxidation and deoxidation.

The form of apparatus now in use is shown on Plate VII. (Figs 1, 2, 3, 4, 5, and 6). It consists of a firebrick muffle (*k*) in which the articles to be coated are arranged; a gas producer (*a*), (somewhat similar to Siemen's) in which carbonic oxide gas is generated by the combustion of coal; a flue (*g*) with a regulating damper (*c*) from

the gas producer leading to and along a passage constructed so as to mix the products of combustion which are led along passages (*i*) and (*l*) to the muffle; a regenerator with fireclay tubes (*t*) around which the heated products pass on their way (down oblong holes (*m*)) from the muffle to the chimney; and a cold air inlet (*v*) to the interior of the regenerator tubes for regulating the supply of air to the furnace.

For the purpose of making the formation of carbonic oxide in such furnaces clearly understood, it may be stated, that, in a common fire oxygen from the air in rising through the thin layer of coal, combines freely with the carbon in the coal and forms carbonic acid (CO^2), but if the fire be made about 2 feet thick, the carbonic acid passing through this thick layer of hot carbon, takes a second atom of carbon and forms carbonic oxide ($C+CO_2=2\ CO$).

In treating cast iron articles without rust, they are brought up to a cherry red heat by a slightly reducing flame, produced by allowing less air to pass through the valve (*v*) than is theoretically necessary for the complete conversion of the carbonic oxide into carbonic acid gas. The hazy appearance of the furnace indicates that this has taken place. This part of the operation (the heating) takes from a few minutes to an hour (according to the thickness of the casting), after which time the air valve is opened and an excess of air admitted until the interior of the furnace is perfectly clear, and only small tongues of flame are visible at the openings (*l*). This is the oxidising operation, which lasts for half an hour with the result of forming magnetic oxide close to the iron, and sesquioxide or rust above it. The air valve and the main outlet to the chimney are then closed, and the articles are submitted to the action of carbonic oxide gas. The gas reduces the film of rust to magnetic oxide, and the operation is completed by a repetition of alternate oxidising for half an hour and deoxidising for a quarter of an hour, for four or five hours, the time varying with the desired thickness of coating.

Wrought iron, and rusty cast and wrought iron are treated together to the heating action described, but the oxidation which, in this case, lasts but a quarter of an hour, is different. No excess of air beyond that which is requisite for complete combustion must be allowed to

enter the chamber. This is secured by keeping the interior slightly misty. The de-oxidisation is then conducted as before described for the space of half an hour, and the time of total exposure is, with these alternations, 5 or 6 hours.

Steel is best coated by alternations of half an hour oxidation and half an hour de-oxidation over a total of 5 or 6 hours' exposure.

Some of the specimens submitted were coated two years ago, and have been exposed, wet and dry, to the open air for from 12 to 18 months, and since then for some months to damp in wet hay and subsequent drying in the air with but the slightest specks of rust resulting. One of them—a sheaf—has been further tested by Mr Tatlock and reported highly satisfactory. The casting weighed 12,400 grains (nearly 2 lbs.), and after immersion in water containing one per cent. of strong sulphuric acid for two hours was found to have lost only four-tenths of a grain of iron (dissolved). On being taken out of the solution, washed and dried in the air, there was no sign of general rusting and but two specks were observed. These specimens having been coated when the process was in its infancy might be expected to be imperfect; the same was the case with the first articles coated by the Barff process.

The process has received the most favourable reports from English and French chemists and engineers of eminence.

The articles subjected to this process assume a beautiful French grey. Those now submitted from the patentees consist of highly ornamental castings in chaste designs, wrought-iron piping, plate, and sections of tee and angle iron, &c., &c.

An examination of the articles coated with magnetic oxide by either of the processes just described will show that the most delicate patterns are coated without injuring the sharpest lines or the artistic effect in the least. No other method of coating can be said to supply this desideratum.

Judging from highly favourable reports and an experience of about two years, these processes seem to rival and outvie galvanizing, tinning, and japanning. When applied in an inexpensive manner to the coating of iron and steel used for machinery, bridges, ships,

and general constructional work they seem destined to ensure a longevity not hitherto dreamed of. The muffles at present are small, but there is no reason to doubt that large castings and plates will yet be treated at as low a cost as to be considered commercially remunerative.

If the result of any process, or of applying any coating will make iron and steel permanently durable or add to their lives, the purchaser should be prepared to allow a considerable per centage for such a very important advantage, by which the cost of maintenance would be almost eliminated, an increased value due to non-depreciation would be ensured, and a sense of security would be realized by reason of the non-decay of the structure.

The author desires to record his indebtedness to the gentlemen named and others for the assistance which he has received in the preparation of this paper.

The PRESIDENT said that at that late hour of the evening, it would be necessary to defer the discussion of the very valuable paper which had just been read. It would be very interesting to the members present to view the specimens ranged upon the table. The coating seemed to be perfect, and the tests which some of them had gone through showed that the system rivalled the most successful plans known for preserving metals. No doubt there would be a little difficulty in dealing with very large things; but that was only a question of time. It was very important that cast-iron could be thus preserved and take the appearance of some other material. He proposed that they should convey their very hearty thanks to Mr Lindsay for the paper he had presented to them that night.

The discussion on this paper was resumed on the 22nd February, 1881.

The SECRETARY read the following remarks from Mr Lyall—The last paragraph of page 84 says, "It has been observed that the loss in thickness of iron plates forming the hull of a ship is accelerated by the friction due to the water," &c. Now, sir, this is what we might

reasonably deduce from a kind of reasoning on skin friction, but, strange to say, we do *not* find it so—at least, such is *my* experience (embracing observations repeatedly made at most of the principal ports in the United Kingdom, at all seasons, over many years). It is not infrequent to find the original scale on well-painted iron plates, when the paint is removed with a knife, as fresh and new in appearance as the day it was rolled. I have found ships' plates, externally, reduced most by actual contact with hard substances, as grounding on or passing over sand, when the sea or river waters, with their various chemical ingredients, have at every such grounding or scrubbing, a *new surface* of plate to act upon. With reference to the wear of plating on the sides of iron vessels, these are mainly brought on, I think, by constant contact with hard substances, as dock walls, and sides of other adjoining vessels, which makes these surfaces a ready prey to the action of water, or water and air, acting on fresh parts after every rub. When dealing with the "Bengal" steam-ship, some years ago, I had that vessel extensively drilled, and a great many plates were renewed, together with the stringers. I was not then aware that the vessel had been previously drilled, or where Mr De Russett obtained his information as given in the paper, but I certainly did *not* find the waste mostly from the *outside*, but from the inside, and the various strakes had *many* sizes where their plates were drilled just as they were exposed more or less to corrosion, or were inaccessible for proper attention. I had an extensive opportunity of again knowing the condition of this vessel's plating, by a very extensive drilling, when very great differences in the thicknesses of the plates forming the same strake were found to exist; but in these cases the deterioration also appeared greatest from the inside of the vessel. It is well known to all marine engineers that the sides of vessels at the coal bunkers suffer by what is termed "pitting." This I am disposed to think is due in no small degree to the falling of the coals against the ship's side by the pitching and rolling motions. It is also well known that spaces over which the cement has been broken or worn off very soon wear down by the wash of the bilge water, especially if that wash carries

solid matter in suspense, and the destruction to the iron so exposed is greatly aggravated by the increase of size in the particles which are washed or rolled about with the motions of the vessel. But if the plates were much worn "by this friction due to the water," and that the waste was thereby greatest on the outside surfaces, we should naturally expect the loss to be reversed from what is given in the table at the foot of page 84—*i.e.*, that the sides would show least loss, the bilges a little more, and the bottom garboard strake plates would be the greatest sufferers.

Mr JAMES M. GALE said it was long since he had come to the conclusion that there was no preservative that would permanently protect iron and steel from oxidation. This action seemed to take place more rapidly in sea water than elsewhere according to the valuable opinions stated in the paper. The method explained in the paper of coating substances by heating in a bath and thereby producing a magnetic oxide, he was afraid could not be applied on a large scale. They would need to immerse the finished article in the bath, for if they put in single plates, it would be found that each stroke of the hammer would lead to the destruction of that portion of the plate. It appeared to him that Portland cement was a very good means of protecting both cast and wrought-iron. They knew that in the United States of America the manufacture of wrought-iron water pipes of very thin sheet iron, coated with cement, was carried out to a great extent, and that these pipes stood a pressure so enormous that they in this country would be afraid to apply to thin sheet iron. It is stated that pipes not an eighth of an inch thick had been in use for 20 years, and that in San Francisco water pipes $\frac{3}{8}$ of an inch thick, lined with a little cement, stood for a great many years with a pressure of 300. In Glasgow they had many pipes in the ground for 60 or 70 years, and the oldest of them were quite useful yet, and if let alone did very well, but they did not stand relaying. He had no doubt the protection from the atmosphere had a good deal to do with their satisfactory condition, and that if they had been exposed to the air, the incrustation from rust would have entered very much more than it had done into the sub-

stance of the iron. After reading this paper, he did not see that anything could be done to prevent iron structures going to destruction.

Mr TATLOCK, Glasgow City Analyst, said the object of Mr Lindsay seemed to be to show the action of the atmosphere upon iron. He had referred to the analysis of paints, and their effects upon iron structures, and he would only notice one or two instances. What ever difference of opinion might be held with regard to the kind of coating used in protecting steel and iron, there could be none in this, that something more was necessary than hitherto for coating in order to protect such materials, and particularly where paints or pigments had been used for such protection. There was scarcely an instance, so far as his experience went, of their being found suitable for such purposes; in fact pure paints and pigments had not had a fair trial at all. He did not know whether any of the other processes mentioned in the paper would be quite satisfactory. He had examined Barff's and Bower's systems, and certainly the coatings had stood well, but the tests were exclusively of a chemical character. As an instance of the very unsuitable materials sometimes supplied he might mention a case in which on analysis of samples he had found 50 per cent. of adulteration, and that of a material which was absolutely injurious to the paint. In fact up to the present time it seemed that the painting of ships, and of large iron structures was pretty much left to the contractor to determine whether the materials put on were of a suitable character or not. Mr Lindsay had done good service in bringing forward this paper, which pointed out the necessity of being careful not only in determining the best means of preventing iron and steel from corrosion, but also in calling attention to the necessity of having the best materials applied in the best way.

Mr T. DAVISON said the system adopted in Paris of covering iron with copper electrically seemed a very good one. All the lamp-posts and other iron structures exposed to the atmosphere were so coated with a layer of copper about the thickness of a piece of writing paper. It was very effective in saving the iron, and needed no painting.

Mr NAPIER SMITH corroborated what Mr Tatlock had said—that paints and pigments had not had a fair trial. Some years ago he had tried precipitated oxide of iron, mixed with pure boiled oil, and turpentine as drier, and found it answer nearly as well for protecting iron as galvanizing, the surface of the iron being first well cleaned as in galvanizing. He found in making trials in attempting to improve upon Dr Smith's system of coating, that the difficulty was, through some action of the air, from scaling off, or by eating through the coating, as if there was something affecting it from the inside as well as the outside. That arose, he believed, from the difficulty in cleaning the surface before coating, and if there was any scale left on these the same difficulty would be experienced. He advocated the use of a caustic alkali as a preventive.

Mr PETER STEWART said he could fully corroborate the remarks made by Mr Smith as to the good protecting qualities of the red oxide of iron when carefully and properly applied. He had used it somewhat largely, and very generally with most satisfactory results. In particular he had applied it to some light wrought-iron girders carrying tramways over calcining furnaces, and though these were constantly exposed to moist acid fumes, after eight years' service they were practically as good as ever. In this connection, with Mr Lindsay's permission, he would beg to correct the remark near the foot of page 101. Red oxide was not got from pyrites cinders. It had been, however, for some time produced from iron scrap by precipitation at one of the Tharsis Co.'s works, and this may have led to the statement. This paint, with all its excellent qualities, had a most unfortunate dull brown colour that did not commend it to purchasers, and its manufacture had been abandoned. He had also to some extent used a bituminous compound containing india-rubber with very good results. As remarked in the paper, gas tar was a very good preservative coating—only it was unsightly and never dried. This varnish, however, did dry rapidly, presenting a beautiful black enamelled surface. His attention had been directed to it in connection with the Tay Bridge, which was painted with it. He had successfully applied it to wrought-iron tubes exposed to strong

acid fumes in a laboratory, and in the case of a wrought-iron tank for hot water, situated in the middle of a large chemical work, the coating, after 18 months' exposure—though not quite so lustrous, is still hard and efficient.

Mr T. ARTHUR ARROL said that the paper contained a great deal of valuable information; but left them pretty much where they were. It would be of great value if it could be settled what was the best coating for iron or steel to withstand our atmosphere, but there did not appear much hope of that at present. In reference to corrosion it appeared from page 81 of the paper that carbonic acid had a great deal to do with it. He had observed an instance of this himself in the case of a roof erected eleven years ago, in which the carbonic acid fumes striking against the inner side of the roof had very much destroyed it. It was to be regretted that compounds of baryta with paints and pigments were so much used. As a colouring body the purest sulphate of baryta was utterly useless, though it was quite as white as pure lead. By mixing boiled linseed oil and a little baryta on a piece of iron it could be shown that there was no colouring matter in the baryta itself. He believed that Mr Tatlock would agree with him that carbonate of lime acted very much the same —which simply gave substance and cheapness to paint, but was of no value in carrying colour over iron to be coated. There was a great deal to be got out of good oil in the coating of iron, as it had the property of keeping the lead against the iron, and causing it to adhere to the iron. If the iron were thoroughly cleaned and oiled, and then a coat of paint put on, it would have a good effect. It was when paint was applied to rusty iron that it was ineffective. He had tried one or two experiments with the Barff and Bower processes, and he could not say that they were very satisfactory. When a piece of iron treated by Barff's process was in the planing machine the coating scaled off. Two pieces of galvanised iron and a piece of Barff and Bower coated iron, and some black oxide scale, were put into a bath of sulphurous acid, which seemed to have little or no effect. He got similar samples put into hydrochloric acid. They had been in since 28th of January last, under the active

influence of acid all the time, which had been renewed. The Barff and Bower coating appears considerably destroyed, while the black oxide scale is not affected. He had also tried one or two experiments with a steel sleeper which had been coated by the Barff and the Bower processes. The sleepers were subjected to a considerable pressure, which had the effect of making the coating jump off as soon as the pressure was put on. He therefore argued that iron or steel prepared under either of these processes would not stand rivetting, nor the vibration of a train going over a bridge, and would not stand bending like galvanized iron. Besides, it would be as difficult to apply either processes to any structure as that of galvanizing.

Mr GEORGE S. PACKER said that some investigators in comparing iron and steel in the same connection, found that the iron corroded faster than the steel, while others found that the steel corroded somewhat faster than iron; but he was of opinion that, taking into account the experiments hitherto made, there was not a great difference between them. However, this matter required a great deal more investigation than it had yet received. There was one small point with regard to the preservation of metal coated by the Barff process, which he might mention. He had coated some screws by this process three years ago, and had kept them in his room, close to the laboratory, and the air of which would contain some acid fumes, since that time, and there was no sign of rust on them; and he believed this method of preservation good for small articles. Any one wishing to compare the relative powers of iron and steel to withstand corrosion ought first to have the scale completely removed; for a scale always acted as a preventative to rust; but when the scale was partially off, there was the risk of corrosion being hastened, owing to galvanic action.

Mr JAMES M. BLAIR said the particular thing with regard to the coating of iron was the preserving of it before it was exposed to the atmosphere. He thought that was very much neglected, and that if once iron were exposed, no coating would prevent its destruction. He had not had much experience with non-corrosive paints. As

regarded the paint put on new iron structures, he thought it ought to be remembered that what were put on in the manufacturer's yard were merely first coats, to protect it till structure was completely erected, and that the final coating was left to the people who had to see to the completion of the works. He thought the only effective way of preserving iron was to coat it as it came from the rolling mill, and so prevent oxidation beginning, for if it began, any coating afterwards was almost useless.

Mr LINDSAY, in reply said—with reference to Mr Lyall's remarks —that the statement in the paper regarding the "Bengal," to the effect that her strakes showed that water-friction accelerates corrosion, was taken from Mr De Russett's remarks in the discussion on Mr E. Clark's paper on the "Durability of Materials." It has been found by Mr Mallet and others that the removal of rust as it is formed increases the rate of corrosion, that iron immersed in highly aerated water corrodes very fast, and that iron alternately wet and dry corrodes fastest. At the 18 feet water line of the "Bengal" these conditions would have a combined action, and it would, under the friction produced by the motion of the vessel, conduce to the result recorded by Mr De Russett. Where the speed is very high, as in the case of torpedo boats, it has been found that paint will not stand the friction of the water, and galvanizing has been adopted in consequence. Mr Gale remarked that no mention had been made in the paper of cement as a preservation coating. No doubt the mention of its use for protecting the inner skin of ships, on page 88, had escaped his notice.

Mr GALE said he wanted to know what was the effect of cement over a period of time.

Mr LINDSAY said that the preservative qualities of cement and lime were shown by many examples on record of iron bedded in the lime used in building Westminster and other Cathedrals. He was aware that cement as a coating for pipes had often failed, but was not acquainted with American practice, as referred to by Mr Gale. Many American engineers specify Dr Smith's coating in preference to any other. He thanked Mr Stewart for his correction regarding

the pyrites cinders of the Tharsis Mines, as his (Mr Stewart's) connection with the company made his information undoubted. The cinders from other mines were, however, used in the manufacture of brown colour, as stated in the paper. Mr Arrol's experiments upon steel sleepers coated with the magnetic oxide seemed to show that the coating, as at present applied, is not suited to steel plates subject to a buckling action. The tests were very severe, and in one case exceeded anything which would occur in practice. It is but a few months since the processes were applied to wrought-iron and steel, the attention of the inventors, he understood, being principally directed to cast-iron, which appears to take the coating permanently. The method of chemically testing the relative resisting powers of the oxide coating and galvanizing, by placing articles coated with them side by side in jars charged with hydrochloric or other acid gas, would not give correct results, as galvanic action would take place between the zinc and the iron, unless the gas be kept in a perfectly dry, neutral state. The tests mentioned in the paper proved that the oxide coating withstood the action of any acid found in the air and in the water of our seas and rivers. The great value of oil as a preservative had been fully treated of in the paper, and he considered that its application to wrought-iron and steel as a coating, after manipulation in the workshop, would conduce to their permanency, as the unstable magnetic oxide scales and rust could then be thoroughly removed and a clean surface presented. If oiled immediately after passing through the rolls the protective effect is lost when the scales come off, which takes place sooner or later.

The PRESIDENT said they must all admit the great debt they owed Mr Lindsay for bringing before them the necessity which existed of coating iron structures properly. They need not take a very long journey in this city without witnessing the rapid decay of cast-iron and wrought-iron structures in our streets, such as the railway bridges, railings, and lamp-posts, although those had been originally coated with paint. And a good instance of this might be seen on the Glasgow Bridge, the lamp-posts being quite decayed.

While abroad he used to have the iron for the works to be erected there coated while in the rolling mill. He had found also that a coating of linseed oil under a high temperature, after the iron had left the rolling mill, was most effective in preventing oxidation from taking place, though the iron was afterwards exposed to the air for many years. They could not do less than pass a very hearty vote of thanks to Mr Lindsay for the very able paper that he had brought before them; and he trusted engineers in this part of the country would benefit by the hints contained in it in their coating of iron structures.

The vote of thanks was heartily accorded.

On Strengthening Malleable Iron by Breaking it, Straining it, and by Compressing it.

By Mr Thomas Davison.

Received and Read 22nd February, 1881.

It may be interesting to the members of the Institution to place before them some experiments which exhibit the rather curious, and to some extent useful effects produced upon bars of malleable iron when they are broken by tensile strains, the effect of repeated strains upon such bars, and also some changes produced by compression.

The most curious effect is that of strengthening the iron by breaking it, to the extent of from 20 to 30 per cent., according to its quality.

The first experiments were made upon three bars of ordinary round rolled iron, one of them of the quality known as S C crown, one of W O mitre, and one of common unbranded English, they were each about 12 feet long and $1\frac{1}{8}$ inch diameter; they were all treated in the same manner as follows:—First, a piece 18 inches long was cut off each end, these two short pieces and also the long centre piece were placed separately into the testing machine and broken by tensile strain; the mean breaking strain of these three was therefore the original breaking strain of the bar in its ordinary condition. Three pieces, 18 inches long, were then cut from the broken centre piece, and one of them placed in the testing machine and subjected to a tensile strain equal to 80 per cent. of the original breaking strain. The strain was then removed and repeated one hundred times; it was then increased till it broke the bar. The second piece was subjected to a strain of 90 per cent. of the original breaking strain one hundred times, then the strain increased till it

broke the bar. The third piece was subjected to the *full original breaking strain* one hundred times repeated, the strain then increased till it broke the bar. The mean results upon the three different qualities of iron were, that the strain required to break the first piece was 9 per cent., the second and the third 11 per cent. *above* the original breaking strain. Allowing for decrease of sectional area caused by the extension of the iron during the first breaking strain, the increase of strength per sectional area obtained in one experiment was as high as 38 per cent.

How much of this increase of strength was due to the breaking of the bars, and how much to the repeated strains, these experiments will not enable us accurately to ascertain, but it is obvious that a considerable portion was due to the repeated strains, as their increased severity seems to be the only cause of the increase from 9 to 11 per cent.

I have not found any experiments upon the effect of repeated breaking of bars except those described by Mr Fairbairn* made at Woolwich Dockyard. According to these experiments the increased strength obtained by breaking a bar was six per cent., so it is possible that all above that amount obtained in my experiments was due to the repeated strains.

There was one circumstance that might influence the results. In all three of the experiments the centre piece broke near one end, so that all three pieces cut from them were on the same side of the original fracture, and these pieces all exhibited increased strength as their position in the bar was nearer to the fracture. I do not think that this could have had much effect, and it may have been accidental, but it is worth noting.

Although Mr Fairbairn mentions the fact that iron is strengthened by breaking he does not give any reason for it, nor have I been able to find elsewhere any explanation. The only reason I can give for such a result is, that when the bars are under strain the atoms of the iron are separated in the direction of the strain, and when

* See "Useful Information for Engineers," page 125.

fracture takes place the sudden complete relief of strain allows the atoms to return towards each other with great rapidity, and in consequence of the momentum so acquired they approach each other more nearly than they did before, and consequently attract each other more strongly, and so offer increased resistance to subsequent separation.

In order to test the correctness of this theory the following experiments were made upon three bars of the same brands, but not bought at the same time, as those used in the tensile experiments :— First a piece 18 inches long was cut off each end of each bar, and these pieces were broken by tensile strain; the mean of each two was assumed to be the original breaking strain of each bar in its ordinary condition ; the centre portion of each bar was cut into two parts, each being about four feet six inches long ; they were then placed in the testing machine and *compressed* in the direction of their length, one of them till it was reduced in length 1 per cent., the second till it was reduced 4 per cent. ; they were then cut into three equal pieces and each piece broken by tensile strain. Taking the mean of two pieces * in each case, the results were, that the bars that had been compressed 1 per cent. were increased in ultimate breaking strength per section area 1 per cent., and the bars that had been compressed 4 per cent. were increased per sectional area 6 per cent., being the mean of the three bars.

We therefore found that forcing the atoms of iron together by pressure sufficient to shorten a bar 4 per cent. greatly strengthens it, and there can be little doubt that if compression be carried far enough it will strengthen the iron to at least the same extent as breaking it by tensile strain. I think it is, therefore, a reasonable conclusion that the strengthening in both cases is caused by forcing the atoms of the iron closer together, in one case by breaking and in the other by compressing the bars.

The increase of strength produced by repeated strains is probably

* The third piece of each bar was annealed to a full red heat in daylight before they were broken, the result was that the annealing had removed all the strengthening effect of compression.

caused by the displacement of the atoms of the iron produced by the strains facilitating their re-arrangement in closer proximity than before, and hence increasing their resistance to change of position in a somewhat similar manner as repeated jars given to a bag of sand greatly increase its resistance to change of form.

The experiments made at Woolwich Dockyard were carried two steps further than those I have described, that is, the bars were broken a third and a fourth time. The results, as far as I can ascertain from the very imperfect details published, were, that by breaking a bar the first time the ultimate breaking strain was increased 6 per cent., the second time 11 per cent., and the third time 21 per cent. above the original breaking strain of the bar in its ordinary condition, the increase of strength per sectional area going up to 50 per cent. The iron experimented upon was branded S C crown. The foregoing calculations are based upon four experiments marked C, F, G, and H, selected as being the most reliable of the ten published.

The great irregularity in these experiments was probably due to the imperfection of the testing machine, as the machine used was no doubt the one described by Professor Barlow, and from his description is obviously very defective. As to the experiments that I have described I need only state that they were made for me by Mr Kirkaldy, which is sufficient guarantee of their extreme accuracy. In describing them I have for convenience used the nearest whole numbers to the exact results, but I have appended to this paper copies in full of Mr Kirkaldy's reports, which can be referred to when more accuracy is required.

These experiments were not made for the sole purpose of ascertaining the effect of breaking, or I should not have complicated them by adding repeated strains to the same bars, but in both directions they indicate a wide field for further experiments. I have not met with any previous experiments upon the effect of repeated strains, although in practice nearly all iron structures are subjected to such strains more or less severe.

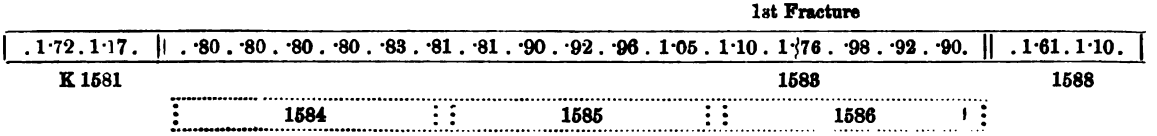
There are two very common opinions that these experiments dis-

prove; first, that wrought-iron is weakened by proving, such as steam boilers, chains, &c, although the strain is greatly below the breaking point; and, second, that iron is injured by repeated strains.

It has been proposed to increase the strength of iron by lateral compression, and iron so prepared (rolled cold) was some years ago offered for sale, but I have not been able to get any particulars respecting it. It would be useful to know to what extent the combination of tensile strain with lateral compression as effected in wire-drawing will increase the strength. The general statement is that iron is increased in strength from 40 to 90 per cent. by this process, but to what sized bars it can be extended I find no data. I hope some of the members will be able to furnish information on these subjects.

Mr ARROL said he had had occasion to test a wheel tie-rod and it gave just the results mentioned in the paper.

Results of Experiments to ascertain the Ultimate Tensile Strength of three Iron Bars, and to ascertain the effects of repeated applications of certain percentages of the Ultimate Stress on portions of same bars that had been previously tested until fractured.



Test No.	Brand.	Original Dia.	Original Area.	Ultimate Stress per Square Inch.		Fractured Dia.	Fractured Area	Difference Area	Difference p. ct.	Extension.	Appearance of Fracture.	Test No.		Applied	Contraction of Area.	Extension.	Appearance of Fracture.
K 1581		1·14	1·020	lbs. 54,353	lbs.	·85	·567	·453	44·4	2·89 in 10, 28·9	Fibrous	K 1584	80 % = 43,287	100 times, broke with 58,985 lbs.	44·4	22·5	Fibrous
1583	SC crown	1·14	1·020	53,779	54,109	·85	·567	·453	44·4	15·0 in 80, 18·8	Do.	1585	90 % = 48,776	100 ,, 60,682 ,,	43·0	21·4	Do.
1588		1·14	1·020	54,196		·85	·567	·453	44·4	2·61 in 10, 26·1	Do.	1586	100 % = 54,109	100 ,, (in 15 minutes) 61,254 ,,	41·7	22·6	Do

. 1·14 . 1·53.	. ·87 . ·87 . ·91 . ·90 . ·96 . 1·00 . 1·07 . 1·09 . 1·10 . 1·08 . 1·01 . 1·03 . 1·21 . 1·28	1·63 . 1·10.	. 1·12 . 1·41.
1589		1591	1596

	1592	1593	1594

																	broke with		
1589		1·12	·985	55,441		·86	·581	·404	41·0	2·67 in 10, 26·7	Fibrous	1592	80 % = 44,151	100 times,	59,684 lbs.	89·7	22·7	Fibrous
1591	WO mitre	1·12	·985	55,870	55,190	·86	·581	·404	41·0	17·06 in 80, 21·3	Do.	1593	90 % = 49,672	100 ,,	60,969 ,,	89·7	24·1	Do.
1596		1·12	·985	54,756		·87	·594	·391	40·0	2·53 in 10, 25·3	Do.	1594	100 % = 55,190	100 ,,	62,243 ,,	38·2	23·4	Do.

1st Fracture.

. ·62 . ·50 ·	. ·54 . ·52 . ·56 . ·56 . ·52 . ·50 . ·50 . ·50 . ·51 . ·58 . ·56 . ·52 . ·55 . ·52 . ·52 . ·66	. ·45 . ·38 .
1597	1599	1604

	1600	1601	1602

																	broke with		
1597		1·13	1·003	53,045		1·01	·801	·202	20·1	1·12 in 10, 11·2	12 % crystalline fissures	1600	80 % = 41,966	100 times,	57,761 lbs.	13·8	12·4	85 % crystalline fissures
1599	No brand	1·13	1·003	53,320	52,457	1·00	·785	·218	21·7	8·62 in 80, 10·8	25 % crystalline fissures	1601	90 % = 47,212	100 ,, (in 14 minutes)	58,394 ,,	17·0	13·0	10 % crystalline fissures
1604		1·13	1·003	51,006		1·03	·833	·170	17·0	0·83 in 10, 8·3	20 % crystalline fissures	1602	100 % = 52,457	100 ,, (in 16 minutes)	59,725 ,,	17·0	12·7	20 % crystalline fissures

Thomas Davison, Esq.,
248 Bath Street, Glasgow.

99 Southwark Street,
London, S.E., 27th March, 1877. } DAVID KIRKALDY.

Note.—Marks were put on the bars every 5 inches, and the numbers marked on the bars (·80, ·90, 1·10, &c.) are the extension in inches of each of the 5 inch portions produced by the breaking strain. These experiments were made April, 1876.

Results of Experiments to ascertain the Ultimate Tensile Strength of three Iron Bars, also the Tensile Strength of the same bars after being shortened under Thrusting Stress.—Tested 26th and 27th February and 3rd March, 1879.

SC crown Dia. 1·12 = Area. ·985

M 4259					M 4261					M 4262					M 4260				
M	Ultimate Stress per sq. in.	Contraction of Area	Extension	Appearance of Fracture.	M		lbs. per sq. in.	M			lbs. per sq. in.	M	Diameter.	Area.	Ultimate Stress per sq. in.	Contraction of Area.	Extension.	Appearance of Fracture.
4259	lbs. 56,406	% 38·3	% 27·2	Fibrous	4261	Shortened *One* % with	41,096	4262	Shortened *Four* % with		62,115	4260	1·12	·985	lbs. 55,442	% 41·0	% 26·9	Fibrous

M 4261	4261	4261	4262	4262	4262
1	2	3	1	2	3

Test No.	Ultimate Stress per sq. in.	Contraction of Area.	Extension	Appearance of Fracture.	Test No.	Ultimate Stress per sq. in.	Contraction of Area.	Extension	Appearance of Fracture.
M	lbs.	%	%		M	lbs.	%	%	
4261 1	56,533	35·2	28·1	Fibrous	4262 1	59,112	33·5	20·1	Fibrous
4261 2	56,531	36·6	28·2	Do.	4262 2	57,390	30·8	18·1	Do.
4261 3	*56,277	38·0	28·6	Do.	4262 3	*55,843	36·5	21·9	Do.

WO mitre 1·12 = ·985 | M 4263 | M 4265 | M 4266

4268	54,203	38·4	26·7	Fibrous	M 4265	Shortened *One* ½ with	lbs. per sq. in. 44,979	M 4266	Shortened *Four* ½ with	lbs. per sq. in. 65,847	M 4264	1·12	·985	55,619	39·6	29·8	Fibrous

	M 4265 1	4265 2	4265 3			M 4266 1	4266 2	4266 3	
M 4265 1	55,164	38·0	24·0	Fibrous	M 4266 1	59,982	32·8	18·2	Fibrous
4265 2	55,249	38·0	23·4	Do.	4266 2	58,600	32·8	18·0	Do.
4265 3	*54,745	40·8	25·2	Do.	4266 3	*55,307	36·5	25·8	Do.

L I.C. 1·12 = ·985 | M 4267 | M 4269 | M 4270 | M 4268

4267	50,924	5·3	16·1	Fibrous	M 4269	Shortened *One* ½ with	lbs. per sq. in. 43,871	M 4270	Shortened *Four* ½ with	lbs. per sq. in. 63,629	M 4268	1·12	·985	51,121	8·7	19 0	Fibrous

	M 4269 1	4269 2	4269 3			4270 1	4270 2	4270 3	
4269 1	52,205	26·3	18·8	Fibrous	4270 1	54,595	18·7	8·4	Fibrous
4269 2	51,816	27·8	18·2	Do.	4270 2	53,497	21·8	11·3	Do.
4269 3	*51,966	29·3	20·0	Do.	4270 3	*50,917	26·4	19·0	Do.

Thomas Davison, Esq.,
248 Bath Street, Glasgow.

99 Southwark Street,
London, S.E., 19th February, 1881.

DAVID KIRKALDY.

The pieces marked * were annealed before being broken.

The discussion of this paper took place on the 22nd March, 1881.

The Secretary read the following from Mr JAMES LYALL:—In addition to the experiments made on repeated breaking and straining wrought-iron by tension as recorded by the late Sir Wlliam Fairbairn, it has been the practice of the American naval authorities to require their chain cables to be made from iron previously broken by tension. This practice, I believe, resulted from experiments made by the Franklin Institution on repeatedly breaking specimens of wrought-iron which give an increase of *ultimate* tension up till a certain number of repetitions had been made on the same material, after which the *ultimate* breaking strains become less at every additional test. This practice in the American Navy has now been discarded for some years. It would perhaps be impossible to obtain anything like uniformity of *ultimate* strength in the different pieces of wrought-iron whose tensional powers had been raised by frequent breaking, or severe tensile straining, prior to its use in a structure—because by the direction of the "flow" of the material, which every one knows who has tested iron, always locating itself after a certain strain has been reached, and before rupture has been accomplished. With regard to the results given by Mr Davison of his experiments, I cannot see these would be of practical value to the engineer unless it can be shown that the material credited with the higher tensional powers can maintain a load, or applications and removals of a load, proportionally greater than can be borne by wrought-iron, previous to such treatment, over the same time. Of this I am very dubious, as by repeatedly breaking the material its elastic powers have been exhausted. I am by no means sure "that these experiments disprove that wrought-iron is weakened by proving," and from some little attention to the results obtained by straining wrought-iron plates with even a very slight lumination (and without the influence of the heat as in a boiler furnace) I am, in the absence of direct experiments, disposed to doubt the value of Mr Davison's results, if applied to rivetted work.

Mr W. J. MILLAR, the Secretary, said that in looking at the results of course there was one thing they must consider in testing

iron—that there was both the strain, and the fracture resulting from the strain; that is, that in a piece that was stretched there must be some difference in form. In testing pieces there was some change shown usually—a narrowing down at the point of fracture where lateral compression evidently took place. Now, in considering this paper it seemed to him that a good deal of the work done in breaking the first part that Mr Davison spoke of, was that of changing the form and not of what might be called the actual fracture; and that supposing they were to take each of these pieces afterwards and hold them in the clips as held before, they had a totally different form to act upon, and a good deal of the second work would be to alter this form back towards the original form, and then fracture would follow. Now, quite irrespective of the fact that any test piece would break at its weakest point, and that we might therefore expect the other parts to give a higher result, he thought that they might assume that secondary broken pieces would give a higher result from the fact of the alteration of form already referred to. Now, on looking at the table on page 124, he noticed that the parts that were cut out of the large piece showed higher results as they were nearer to the original fracture, and he observed that Mr Davison referred to that fact at page 120, as follows:—"There was one circumstance that might influence the results. In all three of the experiments the centre piece broke near one end, so that all three pieces cut from them were on the same side of the original fracture, and these pieces all exhibited increased strength, as their position in the bar was nearer to the fracture. I do not think that this could have had much effect, and it may have been accidental, but it is worth noting." Mr Davison did not seem to put much stress on this, but he considered it very much the key to the whole, and what might have been expected if the bar were a larger one and had changed its form much before fracture. Then if this bar be afterwards cut into pieces, and these pieces again subjected to a breaking strain, one would expect higher results, as each piece was nearer the original fracture, simply because there was more work to

do in changing the condition of the particles to a new form before fracture took place.

Mr F. W. DICK said he had made no experiments on this subject; but he was of opinion that increase of strength was due to the approximation of the particles of the material. It was well known that as the molecules (and therefore the centres of molecular attraction) of any material were brought closer together, the force of cohesion acting between them was increased, and therefore the tensile strength also. In the experiments recorded, the particles would be brought closer together in the tensile as well as in the compressive tests. The strengthening effects of compression was noticed in many instances. It was seen when plates happened to be cold rolled at Newton Steel Works. They were then much stronger than when they were rolled at a higher heat.

Mr JAMES ROBERTSON said that as in wire drawing and in the cold rolling of iron and steel, it was compression accompanied with extension that produced increased strength. The increased strength gained by tensile extension was obtained much in the same way. It was by extension accompanied by the compression of the inner part or mass of the bar by the contraction of its exterior mass. He had observed, in the flexible pipes of hydraulic cranes, that extension of the pipe gave great increase of pressure to the water in the pipe, an experiment easily tried by a lead or india-rubber pipe and pressure gauge attached, and means to extend and collapse the pipe.

Professor JAMES THOMSON mentioned that Mr Bottomley of Glasgow University had got very remarkable results from wires strained beyond the limits of elasticity, nearly to the breaking point. By thus keeping the strain on them nearly to the breaking point, he had got increased strength. It would be interesting if Mr Bottomley would give them a paper on his experiments.

The PRESIDENT said that the experiments contained in the paper were well worthy of being put on record, because it was long considered that testing material up to near its breaking point destroyed it; but to a certain extent Mr Davison's experiments had

fairly proved that to be a fallacy. He was of opinion that that was the cause of his making the experiments. It was now clear that testing iron to a certain strain did not destroy its quality. Mr Bottomley's experiments would also be well worthy of being recorded. He proposed a vote of thanks to Mr Davison for his paper, which was cordially agreed to.

On Steel Castings.

By Mr Frank W. Dick.

Received and Read 22nd February, 1881.

In this paper I propose to give a short description of the steel castings made at the Hallside Steel Works by the Terrenoire process. I will briefly dwell on their properties and the new possibilities which the possession of such a material opens up to the engineer.

Although steel castings are known, appreciated, and largely used by many engineers, still it is a fact that at present a great number are either entirely unacquainted with them, or have conceived totally mistaken ideas about their nature and merits. Much of this misconception has no doubt arisen from the doubtful success which attended the crucible steel castings brought before the public some years ago, as early as 1855, I think, and the almost total want of success in the earlier attempts to produce "furnace" castings of Bessemer and Siemens-Martin metal.

The principal defects in these castings were hardness and want of solidity, and truly homogeneous metal was a rarity. It was found that by crucible casting blowholes were less likely to be formed than in casting on a larger scale by the Siemens-Martin or Bessemer processes; hence notwithstanding the expense and the many disadvantages inherent to the crucible method, it has been somewhat extensively applied, both in this country and on the Continent. In crucible steel castings a high percentage of carbon is employed to insure fluidity in casting, and the subsequent process of annealing is relied on to make them soft enough for working. In spite of every care these castings are often so hard as to be useless.

The accompanying honeycombed specimen shows what measure of

success attended the first attempts at steel casting from the furnace. No matter how strong the material, it is perfectly evident that a casting such as this is quite unsuited for engineering purposes.

A further objection which militated against the earlier steel castings was their want of homogeneousness. Hard spots were of frequent occurrence, surrounded by softer material. These spots appeared as lumps when the casting was turned or planed, and made it almost impossible to keep an edge on the cutting tool.

But these objections are fast becoming things of the past, thanks to the Terrenoire process. It is now possible, and is a matter of everyday practice to get castings made of a material which is soft, strong, tough, and free from blowholes, which can be hammered cold or hot, which welds easily, and in fact, which behaves in every way like superior wrought-iron, with this difference, that it is very much stronger than wrought-iron.

It may appear strange that a simple casting should possess toughness equal to or greater than iron which has been wrought; but it has been found from experiments made at Newton (as already noticed by Euverte) that the properties of a piece of steel (free from blowholes) depend entirely on its chemical composition and its molecular condition, and not on the manner in which that condition has been induced, so that if different means can be found to produce similar conditions in steel, the final result is not affected by the method employed. For castings such means are found in annealing and tempering, the effects of which will be noticed later on.

It has been already stated that the difficulty encountered in early attempts to make castings of Siemens-Martin or Bessemer metal was the formation of blowholes. In the Terrenoire process this fault is entirely remedied by the use of a silicide of iron and manganese. "The presence of a trace of silicon is found to have the singular effect of preventing that violent evolution of gas from fluid steel at the moment of solidification," which caused the objectionable unsoundness. In the fluid steel there is carbonic oxide in dissolution. During solidification this gas tends to escape, but is decomposed by the silicon and silica produced, and afterwards a silicate of iron,

which would remain interspersed in the steel were it not that the presence of the manganese permits the formation of a very fusible silicate of iron and manganese which passes off into the slag. The metal when run into the mould remains perfectly quiet, and a sound casting is readily obtained, possessing a smooth skin and sharp edges.

A principal characteristic of this metal is its extreme toughness. On the table there are exhibited some turnings taken from a mill pinion, which argue the possession of that quality in the material in a high degree. There are also some bars shown which have been bent cold to an angle which few brands of wrought-iron would reach. In one sense this toughness is a drawback—it renders the work of taking off the gates and runners one of extreme difficulty. It is of no use to attempt to "nick" them round and break them off, they must be turned or slotted off. The breaking strain varies according to the nature of the casting and the subsequent treatment. Plain castings of some size may be made of very soft metal, while more intricate ones require to be made rather harder, but in no case is the metal really "hard," *i.e.*, too hard for tooling. In general the variation does not exceed six tons per square inch, and ranges from 29 to 35 tons per square inch. The extension varies from 36 to 12 per cent. in lengths of two inches, and from about 17 to 6 per cent. in lengths of eight inches parallel. Stronger qualities can be made, but any increase in strength is gained at the expense of toughness. The elastic limit I have invariably found to range from $\frac{1}{2}$ to $\frac{5}{8}$ the breaking strain.

The ultimate character of the steel depends much on the treatment to which it is subjected after being cast. I do not refer to the practices of long-continued annealing and heating in contact with oxides of iron, often adopted in connection with crucible steel castings, but simply to the effects of heating and cooling in different ways. Before you are three samples of steel taken from the same casting. The first, which exhibits a largely crystalline fracture, shows the steel simply as it is cast; the second, which is much more compact in appearance, has been heated to a cherry red and cooled gradually; the third, which has a very close texture, has (after

annealing) been again heated to a cherry red and cooled in oil. Beginning with the casting in its original state, the effect of re-heating and cooling gradually is to greatly increase the toughness and the extension, to increase a little the breaking strain (except in very soft metals, in the case of which it is not much changed) and to decrease a little the proportion which the elastic limit bears to the breaking strain. By re-heating and dipping in oil the breaking strain and elastic limit are increased, the toughness and extension are diminished, and the metal is compacted. It will be noticed that the effect of dipping in oil appears to be analogous to that of hammering; much the same changes are induced. I have here two bars, 1 inch square, cut from the same casting. One is annealed simply, the other is annealed and dipped in oil. They were tested transversely with three feet bearings. The annealed one took its first permanent set with a load of 0·4 tons applied midway between the supports, and finally sunk with a load of 0·7 tons. It has been bent through considerably more than a right angle, and is not broken. The one dipped in oil took its first permanent set with a load of 0·5 tons and sunk when loaded with 0·9 tons, breaking when bent through 90°. These bending tests corroborate the results of many tensile tests with regard to the increase of strength and decrease of toughness due to cooling in oil.

The art of steel founding is now so perfected that it is scarcely too much to say that anything which can be cast in cast-iron can be cast in steel. The applications of steel are already almost innumerable. From it are made crank shafts, thrust shafts, connecting rods, eccentric rods, crossheads, guides, propeller blades and bosses, and even the nuts for them, gearing of all descriptions (the toothed wheels already cast ranging from a few pounds to as much as 12 tons in weight), carriage waggon wheels, locomotive bogie centres, rolls and rolling-mill gear, anchors, hydraulic cylinders, steam hammer faces and anvil blocks, and so on.

It is seldom that a working stress of more than one ton per square inch is allowed to be put on cast-iron. Hydraulic rivetters of Hallside steel are in daily and satisfactory use under a *working stress*

of 14 tons per square inch. Here then we have a material which can be moulded to any shape as readily as cast-iron, and which is stronger and tougher than wrought-iron. Moreover, like wrought-iron, it can be wrought under the hammer and welds with facility.

It is almost unnecessary to point out the advantages which accrue from the possession of such a metal. The simple process of casting will, in numerous cases, displace the more difficult method of forging. In cases, also, where the engineer is tied to weight (as often instanced in marine engines) it is evident that the use of a material which is at least six or seven times stronger and more reliable than cast-iron offers one means of securing lightness without the sacrifice of strength.

I will conclude with one or two examples of the relative durability of cast-iron and steel. A cast-iron worm in connection with the turning gear of one of the steam cranes in the foundry at Hallside was found to grind itself away in from two to three days. The steel worm by which it was replaced lasted eight or nine months. A driving pinion in the rail mill when of cast-iron usually gave way in from one to three weeks and failed through breakage of the teeth. A steel pinion, made to replace one of these, was taken out at the end of two years' continuous work, and then only because the teeth were so much worn that they did not gear properly.

Steel is invaluable in rolls which are much cut into by the sections they are intended for. In plain rolls the surface lasts well. The method of chilling is not used, but the hardness can be increased by increasing the carbon.

It should perhaps be mentioned that the shrinkage of steel castings is about $\frac{1}{4}$ inch per foot.

The discussion of this paper took place on 22nd March, 1881.

Mr DAVID ROWAN said that while he had considerable experience in using steel castings, he could not give any information as to the mode of casting steel, or in reference to the material itself. He was quite aware that steel castings made as described by Mr Dick had about three times the strength of cast-iron, and that the steel blade of a propeller was as workable as any cast-iron they could have.

The castings of steel that he had had were perfectly solid, and had no blowholes in them, nor any defects. The skin was a little harder, and had sometimes a rougher surface. The material was not hard, and in turning it, it was found to be a fine elastic material, and safe at the same time. He thought that in any piece of machinery where great strength was required, without defect or flaw or blowhole, that a steel casting was the best material to use in order to get what was wanted. He had had a great many propeller blades made of this material, and they had been all what might be called perfect castings, and the material of the finest description.

Mr HALLEY said that in connection with some of Mr Dick's remarks in the paper, and thinking they might be of interest to some of the members, he had brought with him that evening a few pieces of steel cut out of the "gate" of a large cast-steel piston, made at the Hallside Steel Works. The "gate" referred to was about 14 inches diameter, and out of this was turned a disc about one inch thick, this disc being afterwards divided into a few strips, two of which had been, as they would observe, bent cold under a steam hammer on a V block to a considerable angle before breaking; others of the pieces had been manipulated by a smith at a bright red heat, and after being drawn out under the hammer and allowed to cool slowly had been bent round into a flat horse-shoe shape. This same steel also tempered easily, and, he expected, would make a fair turning tool.

Mr GEORGE RUSSELL asked whether it was possible to weld these steel castings to bar or forged iron, as this might be necessary in repairing in case of accidents. He had used these steel castings for pinions, worms, and wheels, and they had all been first-class. He considered it a great acquisition to the engineer that he could obtain this material.

Mr GALE said he had used some steel rings for joining water pipes in the city, and he thought it very wonderful the amount of strain that material would stand. They were getting it at the remarkably low figure of 14s per cwt. If water pipes could be made of this material they would be much better than cast-iron,

and much more trustworthy. The material was most unexceptionable.

Mr MAYER suggested that, as steel castings could be used as the raw material out of which to make turning tools, part of the piston exhibited by Mr Halley should be sent to Hallside Steel Works to be analysed, so as to see what amount of carbon it contained.

Mr HALLEY thought there was no need for this, seeing the piston was cast at Hallside, and no doubt they would have analysed it. He asked with regard to the annealing of these steel castings, as to the efficient depth that it reached. He had found in some cases the skin was easier cut than the material was, three-eighths of an inch in.

Mr DICK in reply said the criticism and remarks on his paper were of so favourable a kind that he found his task was almost finished when he had done reading the paper. Mr Rowan had delivered what might be called a eulogy upon the material of steel castings, and such criticism as his would go far to further its use. The piston, part of which had been shown by Mr Halley, had been manufactured by the Steel Company of Scotland. The pieces produced were taken from the "gate," which was 12 inches in diameter, and were bent at the most unfavourable part. Mr Halley spoke of making turning tools from the steel of the piston. Castings of the diameter and small thickness of that piston had to be made harder than thicker ones would require to be. The material of the piston might "temper" or it might not. It was not manufactured with the intention of making it suitable for tempering. There was enough carbon present to admit of a temper being taken, but the other ingredients made it uncertain whether it would take a temper or not. He could not tell whether they could weld steel castings to wrought-iron; but he would experiment upon the matter immediately. Of course they could cast steel in any shape, so that there was less necessity for welding the two materials together. If there are any flaws in steel castings they must be on the surface. The steel joint-rings of cast-iron pipes are rolled, not cast. They carefully analysed the charge of every casting, including that of the

piston referred to. He believed the carbon was ·42 per cent. He would like to ask Mr Halley whether he had any difficulty in welding the specimens shown by him.

Mr HALLEY said a bar 1¼ inch by 1 inch had been welded with a good long scarph, and it had welded as easily as a piece of soft malleable iron, and so well that the weld could not be seen.

Mr JAMES GILCHRIST said the Board of Trade and Lloyd's had insisted that no steel should be used in shipbuilding that was welded; so he took a lot of parings and rolled them into a bar of steel 1½ inch in diameter and broke it, twisted it about, and then welded it. These parties were shown this beautiful bar, and could see no mark of welding on it, and from that day to this they do not stand in the way of using welded steel.

The PRESIDENT thought Mr Gilchrist was to be congratulated on making such a revolution on the parties named. It was something to get them to move in any way. He thought there could be only one expression of opinion in reference to the information given in the paper. It was a very valuable paper, and showed what a useful material the engineer now possessed compared with what he had a few years ago. He recollected about 25 years since that there were some very heavy locomotives being made in this country, for the Austrian lines, and the outside cranks which were double, were specified to be of steel. He knew for a fact that the whole of the manufacturers of steel were applied to, to make them; but none of them had plant for the purpose, and they ultimately had to be made of Bowling iron. Now we have a material much stronger than the best wrought-iron, and which can be cast. The revolution in the manufacture of steel is wonderful, and it was difficult to say what progress it would yet make. It was now used greatly in the building of ships. Thirteen years ago he put in a steel boiler into Fairfield Works, its evaporative power being slightly in excess of the malleable iron boilers put in at the same time. This steel boiler was still in use, and was in perfect order. He believed this material would be greatly used in the future, and entirely displace the use of iron for engineering and shipbuilding purposes. He proposed a vote of thanks to Mr Dick for bringing the paper before them.

Note received from Mr Dick, 14th April, 1881.

I have since tried if wrought-iron could be welded to Hallside steel castings, and I find that it can be, easily and perfectly. A cast connecting rod (for a small vertical engine) was taken rough from the sand, and cut in two at the middle of its length. To one part there was welded a round bar of wrought-iron, and to the other half a rolled bar of mild steel. In neither case was any difficulty experienced, and the welds were perfectly sound. The material of these castings, then, can be welded easily to itself, to rolled steel, and to wrought-iron.

On a New Patent Water Meter and Hydraulic Motor.

By Mr DAVID JOHNSTON.

(SEE PLATE VIII.)

Received and Read 22nd February, 1881.

WATER METERS may be divided into two distinct classes—viz., differential and positive. In the former the quantity of water passed is calculated by its giving motion to a screw or wheel, a given number of revolutions of which should pass a known quantity of water. Of these we have good examples in the Siemens and Deacons meters.

In the positive meters again, a cylinder and piston are used, the cylinder being of a known cubic capacity, and the amount of travel of the piston, or number of strokes, being registered by means of suitable counting gear on a dial, the quantity of water passed may be ascertained to a very near percentage—say, from one to two-and-a half per cent. As examples, we have the well-known Glenfield meter, the Manchester Co.'s meter, and the one before us to-night.

Could a water meter on the principle of the screw be thoroughly relied upon, it would be by far the best form of meter, as there are no valves required, and a simple worm and worm wheel connects it to the counting gear. It takes up little room, and the cost is a mere fraction of a positive meter. But I believe they are not reliable, especially when the water is run off slowly. In the Glenfield meter one cylinder only is used, and the piston is reversed by a three-way cock actuated by a lever with a weighted end, which lever is tilted by teeth on the piston rod—the momentum acquired by the weight reversing the valve, and the counting gear is wrought also by teeth

acting on double ratchet wheels. In the Manchester meter a slide valve is placed on the cover, which is wrought by a small horizontal cylinder, the valve of which is actuated by projections formed on the piston rod through its being flattened part of the way, and the counting gear actuated by a small projecting spring attached to the piston rod, which strikes a ratchet wheel, putting it round a tooth at each stroke.

What I claim for the meter before you is great accuracy in the measurement of the water, almost frictionless in its movement, simplicity in the working parts—all being lathe work, and, as the pressure is equal—or nearly so,—no stuffing boxes are required. A reference to the diagram will explain the construction of this meter.

It consists, first, of two cylinders A and A^1. A^1 is shown in section exposing a very light piston, B^1, made of gun metal, which has no packing, but is rendered water-tight by a long bearing.

I have found that less than one pound pressure on the square inch is sufficient to work a small meter of 3-in. diameter of cylinder.

I consider that the extra function of a packing, which would increase the difference of pressure between the inlet and outlet ends, would be more of loss than gain.

The piston moves almost frictionless from end to end of the cylinder until it is brought to rest by the collars of the brass tubes e, after having pushed the tappet E^1 before it and reversed the valve for the cylinder A, when the piston B would then travel till it reached the other extreme end of its cylinder, when the valve for the cylinder A^1 would be reversed, and the piston B^1 would again travel to the other extreme end of its cylinder. This series of operations would be continued so long as water was being drawn off, as hereafter explained.

Each cylinder is of a known cubic capacity between the collars e, e, which bring the piston to rest, where the full water pressure still holds it till the other piston (the valve of which it has just opened) has reached its destination, and discharged the measured quantity of water contained in its cylinder.

The number of strokes is registered by the lever E^2, which trans-

mits the motion from the tappet E^1 to the valve rod D^1, having formed on it two pallets F^1 and F^2 which strike into the teeth of the crown or pallet wheel F, each stroke of the lever turning the wheel the distance of half-a-tooth, as seen in the models now before you. The pallet wheel has twenty teeth, and the cubic capacity of the cylinder is one-eighth of a gallon. There are two fills of each cylinder discharged to turn the wheel one tooth—that is, half-a-gallon,—so that each revolution of the wheel is ten gallons measured.

This wheel communicates motion to a train of wheel-work by a small spindle f, passing through the stuffing box g. The wheels and pinions are geared 10 to 1, so that, starting with 10 gallons on the pallet wheel, we have a hundred on the next, a thousand on the third, and so on to any required amount; and, by fixing indices on the spindles, we read off, at a glance, from one to millions of gallons, if necessary.

The water is admitted to a chamber a, formed between the cylinders, which, in the diagram before you, are formed of two brass tubes fixed in a cast-iron box, but may be cast solid and the chamber cored out between them. This chamber communicates with the cylinders by a brass tube or valve seat at each end for either cylinder, leaving perforations in them opposite the ports, and secured water-tight by the covers which surround them by spaces forming the ports leading to their respective cylinders.

These brass tubes form the chambers in which the piston valves work. The piston valves consist of small rods D^1 and D^2, at each end of which the pistons are afixed, the rod or valve top extending to the tappet levers. By referring to the diagram it will be seen that the piston is at the extreme end of the cylinder A, the tappet E having pushed the lever E^{11}, raising the valve rod D^2, allowing the pressure to come in on the left side of the piston B^1, which has now reached that position where it has pushed the tappet E^1 through half its travel, and the piston valves of the cylinder A are entirely covering the ports, and as it completes its travel the valve towards the left of the cylinder A will be gradually opened to the pressure and the one towards the right to the discharge; the piston B will

then travel towards the right, discharging its measured water into the casing C^1, from whence it passes through the pipe C to the tap, and when it has reached the end of the cylinder the valves for A^1 will be reversed and so on, the number of strokes being registered as before explained. I have found that no packing is required either for the tappets or piston valves, as there is not more than one pound pressure on the square inch difference between the pressure side and the discharge chamber between which they communicate.

The meter can also be utilized as a pumping engine for a mine. The cylinder has a gun metal liner, and the pump barrel is also lined with gun metal. The piston rod is connected direct to a crosshead corresponding to the lever E^{11} on the meter, and connected rigidly with the valve rod. The beam levers at each end correspond with the levers E^2 on the meter and are actuated by the main piston striking them at the end of each stroke. At the other end of the levers from the tappets they press on the ends of the valve rod, admitting the pressure to that side of the piston, which will cause it to alter the valve and reverse the motion of the piston, the movements all being similar to those of the meter.

When applied as an organ-blowing engine the only difference is, that the rod comes through the stuffing-box, and there is only one tappet and beam lever, the tappet being pushed on the one side the same as before explained, but drawn back by a small rod attached to it with a nut on the end, which rod passes freely through a hole in the piston rod till the nut catches a plate with a small hole in it on the end of the rod which pulls it back. The little models exhibited are wrought in this manner.

The discussion of this paper took place on the 22nd of March, 1881.

After Mr Johnston had made a few recapitulatory remarks,

Mr JAMES M. GALE said he thought Mr Johnston's meter a very good contrivance for measuring water. The only objection he had to it was, that it must be costly at first compared with some other water meters, as there were two cylinders in it; but not so costly as

some of those proposed to be used in Paris. He believed it would be a first-class meter.

Mr FOULIS asked how the pistons were kept tight?

Mr JOHNSTON replied that in one of the models before them the cylinders were of cast-iron, the pistons of brass, with a long bearing, but very thin, so as to be as light as possible. He wrought this as an engine with a head of water of 8 inches. The theory he had acted on was this:—A long tube with a very small bore required a great pressure to force the water through it; and if a piston was accurately fitted with a long bearing, it was merely like a tube of infinitesimal bore, and would require much greater pressure to force the water between the cylinder and the piston, than propel the piston to the end of its stroke. Then as they saw in the two covers, these valves were worked inside the covers, and the only difference of the pressure was the actual friction of the machinery, and when that was reduced to a 1-lb. or ½-lb. pressure on the square inch, with anything like a good fitting piston there was more pressure between the sides of the piston and the chambers than that required to carry the piston to the end, and so the water was not allowed to pass. He had used packing at first, such as cords, gutta-percha, &c., and had also tried solid pistons of *lignum vitæ* with india-rubber corrugated cushions pressing out brass rings, but he found that the *lignum vitæ* swelled and so would not work in the cylinders. He decided then on using nothing but solid metal, unrustable, and as light as possible, and had found that any little water that escaped merely acted as a lubricant.

A vote of thanks was then passed to Mr Johnston for his paper.

On the Technical Education of our Young Engineers, Shipbuilders, and Artizans.

By Mr ANDREW JAMIESON, C.E., Principal of Glasgow Mechanics' Institution.

Received 18th; Read 22nd March, 1881.

BY the term "Technical Education," the author wishes it to be understood that he means not only theoretical education, but the practical workshop training.

The importance of this subject cannot be over-estimated in a city like Glasgow—so pre-eminent for her shipbuilding and many branches of engineering; and it is therefore to be hoped that the practical opinions of her best engineers and shipbuilders may be brought to bear on the discussion.

In the first place, the author proposes to give an outline of the system generally adopted in Scotland for the *workshop training* of our young engineers, shipbuilders, and artizans—with its *advantages* and *disadvantages;* to point out where, in his judgment, it may be improved, and what changes are required to suit the case.

In the second place, he will allude to the present opportunities in Glasgow for the *theoretical training*, wherein these opportunities are lacking, and how they may be improved.

Thirdly, and lastly, he desires to call upon the leading engineers and shipbuilders of this Institution to recognise and foster, by their influence and support, the theoretical part of the technical education of our young engineers, shipbuilders, and artizans.

Let me picture to you the case of a youth of 15 years of age, of average ability, and trained in one of our public schools; the son of respectable, well-to-do parents, who are capable of giving him any professional education he may choose, including a complete Univer-

sity training; but who, having recognised in their son a natural taste for engineering or shipbuilding, decide to send him to one or other of the leading and eminent firms in this city or surrounding district. What do they do? They communicate with the manager or owner of some works where they can bring to bear personal or indirect influence, introduce the youth, pay—if necessary—the desired premium, and leave him to complete a term of five years in the shops or yard, without, as a rule, having the slightest idea that provision should be considered or entered into for simultaneously carrying on and advancing his theoretical knowledge. In fact, having once got their son attached to a work, they congratulate themselves on having done their duty.

Well, the young man enters the workshop; and now that formal binding apprenticeships and indentures are almost universally abolished, and premiums are few, we will trace his course for the five years he has to undergo pupillage, and sum up the final results.

If his parents have sufficient interest with the firm to which he has been attached, he may enter the pattern shop, and, doing so at the age of 15, without any previous knowledge of the use of tools, or laws which regulate their action, to say nothing of the growth, seasoning, and relative strength and adaptability of different kinds of timber, he has, to use the shop parlance, "to hold the candle" for the first ten or twelve months. In other words, he has to get up in time to reach the works by 6 A.M., light the fire in the pattern shop, sweep the floor, carry water for the men, stack wood, dust and arrange old patterns, and generally fill the place of an errand boy, with occasionally an odd job, such as "flanging a pipe," turning a few "core prints," or making "sodgers" for the moulder. He gets to his home about 6 P.M., after a somewhat depressing day's work of 9½ hours, glad to throw off his working clothes, and seek some enjoyment; but seldom does he think of study. In fact, can you wonder at it? In this way he goes on, and actually picks up information which will be of great use to him in after years, but in a terribly slow and uninteresting style. By the time he has been two years and a half in the pattern shop, he will no

doubt, if he has any go, and aptitude for work, be capable of handling and sharpening his various tools with more or less precision, reading a drawing, and carrying it into execution in a way which may pass muster; but it is only in the second and third years, according to the present system of training young men, that he can expect, with average ability, to learn this part of his work; and the author ventures to say that not five per cent. of the lads who thus enter the pattern shop, have their attention ever directed to the fundamental principles which regulate the form and temper of edge tools, the natural laws which determine the selection of one kind of wood in preference to another, the strength and best arrangement of materials, the percentage amount to be allowed for shrinkage in iron and brass castings, to say nothing of the manner of procuring and cost of these materials. Well, perhaps in some exceptional cases there is an advantage in this form of training, and if our young friend is really a boy who has a distaste for books, the above-mentioned routine work will do him good; but to a youth of spirit and ambition, it is decidedly depressing. During the two and a half years, he has hardly once had pointed out to him by his foreman, and still less by the manager, the advantages that might be derived, not only to himself, but to his firm, by *studying drawing* in all its branches, mathematics, theoretical and applied mechanics, chemistry, &c.; nor have his parents or friends in all probability ever dreamt that such was necessary, or even advantageous.

He now seeks a change; having got tired of wood, he is anxious to try his strength upon the harder metals, and desires a transference to the turning, fitting, or erecting shops, which, if not then granted, the lad continues for another half year or so in the pattern shop; and at the end of three years he again makes application, and is now received into the fitting shop. There, he is no doubt of much more immediate service than if he had entered at the commencement of his time, and thus is so far able, in a comparatively shorter period, to pick up the use of his tools—the hammer, chisel, and file. But still, nevertheless, he has to do a good deal of drudgery—"mechanical drawing," in the shape of hauling pieces

of machinery from one part of the works to the other, or from the shop to the building yard if in a marine engine works—and it is only after a year or so in the fitting shop that he is entrusted with a complete kit of files and chisels. However, he works away, believing all the time that he is learning the profession of engineering, and it is only in his fifth year, and when he is upwards of twenty years of age, that he begins to realise that he knows little or nothing of the principles which regulate the design and cost of machinery. If fortunate (and he must consider himself very fortunate if he gets into the drawing office), he soon finds that here he has to begin at the beginning, and that the leading draughtsmen, no more than his foremen in the shops, have time, nor are they interested, nor directed to instruct him how to manipulate, calculate, and design; so that he has here, as he had in the pattern, fitting, and turning shops, to pick up as best he can, by slow degrees, the various details of the office. He gets tracing after tracing to do without being led to think why this, that, and the other piece of machinery has been so designed and arranged; and it is only after a year or eighteen months in the drawing office that he can be trusted to get up a set of *scale* drawings, while all the minutiæ of calculations and designs are to him a sealed book. He now begins to reflect, and to say to himself, "Is it for this that I became an engineer?" and he now sees, at this late hour, wherein the fault lies, and how very much more interestingly and instructively his term in the workshops might have been spent, had he only combined it with a course of study. He is now twenty-one or twenty-two years of age, and he determines to read up, and to attend evening classes; or, if thoroughly disgusted, he seeks relief to his chagrined feelings by going to sea.

You will observe that our young man has, during the five years that he was engaged at work in the shops, only become a fair mechanic, and that, were he then to leave his employers, he could only occupy a position in any similar works as a journeyman patternmaker or fitter, at ordinary weekly wages, or go to sea as a fourth engineer, and that he has in no sense learned Engineering

as a profession. In fact, all this time he has been forgetting the very elementary education which he received at school prior to his entering upon his pupillage. The few hours that he has had to himself, after leaving the works until he goes to rest, have been spent (in most cases) in seeking enjoyment. He is very fortunate indeed if these few evening hours, with Saturday afternoons and Sundays, can have been spent at home, because his mind, manners, and demeanour will have been thus no doubt considerably polished and improved; but there are comparatively few of our young men who can enjoy this modifying influence, coming, as they do, from all parts of the country to this busy centre of industry, to study Engineering. The author believes he is not drawing an exaggerated picture when he states that as a rule young men who come here at the age of 15, hoping to learn the profession of Engineering by serving a term of five years in the workshops, with the full conviction that at the end of that time they will be able to fill a good position, are sadly mistaken; and this arises, not from any want of ability, but from the mere fact that they have all this time *entirely neglected study and theoretical training*, which now-a-days, more than ever, constitutes an important factor of an engineer's education.

The system is therefore deficient; and wherein does this deficiency lie? We most emphatically say, that it lies in the want of a requisition by masters for theoretical as well as practical training. Take either of the professions, law or medicine. A young man entering one of these, has enforced upon him, day after day, by the leading members of the profession, the necessity of combining practical training and routine duties in the office, or wards, with the scientific study of the principles which constitute the basis of his profession; and he cannot expect to be recognised or admitted within the circle of the profession of which he aspires to become a useful member, until he has shown competency in understanding and mastering these principles.

It is quite different with engineering and shipbuilding. Any one can call himself an engineer or shipbuilder, even though he may be only working away at the hammer and chisel for weekly wages, or

occupying a minor position in a drawing office. Were it made obligatory by masters and employers that each youth who is about to enter their works for the purpose of undergoing a pupilage to engineering and shipbuilding should know the elementary principles of drawing, mathematics, and physics, with a fair knowledge of the use of tools, such as how they should be tempered, ground, and set, as well as a little about the strength of materials, and steam, and that he would require to extend this knowledge during his said pupilage, either by leaving the works entirely for a couple of winter sessions to attend the University, or other technical day college, or, if that be impracticable, by attending evening classes; and that he should require to produce, before his term was up, certificates as to this competency in theory from some well-known school or college, recognised and patronised by the profession, the masters and employers would find increased benefit from the work done by their young men. The young men themselves would thus be trained to think, reflect, and consider their manual operations in a totally different light, and go through with their work in a smarter and more pleasing manner; while the profession would be greatly benefitted by having, in the course of say four or five years, a class of young foremen, draughtsmen, and ultimately managers—men capable of designing and carrying on work one stage in advance of what it is at present—and at the same time raise the standard of the profession in the eyes of the world at large, to say nothing of keeping our arts and manufactures freer from foreign competition.

The author does not for a moment depreciate the necessity for workshop training. He has gone through it all himself, in its various stages of pattern-making, turning, fitting, and drawing office, besides having had to carry out engineering work abroad. In fact, he considers a term of four or five years in the shops and drawing office, in the shape of pupilage or apprenticeship, as absolutely necessary to make a good practical engineer or shipbuilder. But what he finds fault with is the almost entire absence of demand for theoretical training by the profession from our young engineers and shipbuilders. Nor does he advocate a very high

standard of mathematical and theoretical knowledge, for he is convinced that such is not absolutely required in practical engineering and shipbuilding; but rather that young men should be taught leading principles, and led on to deduce facts from these by experiments and their results. The factors of safety required for general work are so large and various, that those who go in strongly for mere theoretical calculation and reasoning are equally liable to mistake with those who entirely depend upon rule of thumb, copy, and practice.

The happy medium can only be arrived at by a suitable combination of a fair knowledge of theory with good workshop practice.

If we consider a youth desirous of learning shipbuilding, we shall see that his case is in some respects better, and others worse, than the young engineer. He will have to work with his hands at joiner work, and ship-carpentry, for three or four years, with pretty much the same chances as the latter, as far as special instruction in the laws which regulate the use and form of his tools, the selection and cost of materials, or the best form and shape of boats and vessels is concerned. Probably he will then have a better chance of being admitted into the drawing office or loft for the last year or two of his time, from the fact that more ships' drafting is required than formerly, and there are not so many in the field against him, also now that iron shipbuilding has become the rule, a greater proportion of the outdoor work has to be done by less scientific and highly-trained labour, and less is left to rule of thumb calculation than in the bygone days of wooden shipbuilding. In former days each young man was strictly indentured for six or seven years, and it was considered necessary for him to become not only a fairly skilful ship-carpenter, but well up in rigging and sail-making, and he had often to go to sea for a voyage or two, to actually see for himself how the work carried on in the yard stood the test of heavy seas and rolling billows. In those days a premium or strong interest was required to get into the drawing office, while now premiums are seldom demanded; and there is a class of men rising up who are content to

be ship-draughtsmen for years, or life, without taking active part in the operations going on in the yard, and who never dream of going to sea as carpenters for experience.

It would do every young man good who wishes to be a thorough shipbuilder, were he to have a turn at the iron work as well as the wood, for it would no doubt render him more capable of forming a correct opinion of good and bad workmanship, of the time required to do work, of difficulties attending certain classes of work, how to handle iron workers' tools and material, and what the former are capable of performing, as well as how to avoid expensive and impracticable plans.

A young shipbuilder will find it much more difficult than a young engineer to attend classes where he can obtain the desired theoretical knowledge bearing on his profession, for at present (as far as the author is aware) there is no provision made at any of our Scotch Universities or Institutions, nor has that much desired "experimental tank" been formed where a young, ambitious naval architect can attend lectures and experiments on shipbuilding art and design. He should, however, not lose the opportunities at his disposal of being well grounded in the principles of drawing, including practical, plane and solid geometry, analytical geometry, machine construction drawing, mathematics, physics, steam, and the principles of applied mechanics, including strength and selection of materials, which are open to him at the University, or one or other of the evening institutions working under the Science and Art Department; but here he must stop, or read up privately for himself, the principles of building construction as applied to naval architecture; to say nothing of the scientific principles which regulate the speed, resistance, and curved lines of ships, and consequently more must depend upon his own energy and ability for self-culture (in the strictly theoretical part of his profession) than in the case of the young engineer; besides good treatises on naval architecture are not so cheap or numerous as those treating of applied mechanics and steam or practical engineering.

We now come to the young artisan, who, to take an example may

be a lad of 13 or 14 years of age, who has received his education at one or other of our Board Schools.

We do not of course advocate for him such a high standard of theoretical knowledge as in the case of the young engineer or shipbuilder, nor do we ever expect that a youth, who starts in life with the object of being a mechanic or artisan for life, or at most a leading hand or foreman, will trouble himself much about the scientific and theoretical principles which regulate the design and construction of his work, nor would it be well that he should. Nevertheless, we are confident that were an elementary knowledge of drawing, mathematics, and applied mechanics (the latter more especially with regard to the use, shape, best form, and temper of his tools) demanded of him by his employers, there would be not a few who would come up to the mark and who, when the interest attending the attaining of such knowledge had once been started and set in motion, would probably desire to enlarge that knowledge to the general benefit of themselves and their employers by increased ability and aptitude for understanding and carrying on the work assigned to them.

In order to be a good artisan in any particular kind of work, a lad must serve a full pupilage of at least five years at it alone, otherwise he will not acquire that expertness so necessary in the use of his tools, and were he to combine this with an attendance at evening classes for the above mentioned subjects, his aptitude for arranging and effecting his work would no doubt be considerably increased.

No doubt as matters at present exist we can only expect but a small per centage of the artisan class to take advantage of such opportunities as may be offered to them for mental training, but were employers of labour to request or even advise their young artisans to attend evening classes for mechanical and geometrical drawing and so forth, and patronize in a larger degree the various evening class institutions, including in the "lines" which they usually give at the end of a lad's pupilage, a short note or statement as to whether he had taken advantage of these classes as well as faithfully performed his work in the shop, in the case of those

worthy of such affixes to their character, there would not be wanting many hundreds who would willingly comply who now never think it necessary, because it is not prominently or thus forcibly brought to their notice and understanding, while the average standard of our higher class workmen in this part of the country would undoubtedly be raised.

At the commencement of this paper the author promised to consider the present opportunities in Glasgow for the theoretical training of young engineers, shipbuilders, and artisans, to point out wherein these opportunities are lacking, and how they may be improved. In the first place, we have the University conferring its certificates and degrees of C.E. and B.Sc. upon those young engineers who are so fortunate as to be able to spare the time and money required in attaining these much desired and coveted titles. And he cannot too strongly advise not only all young civil engineers, for whom the classes are at present more especially arranged, to attend the University, but also all young practical engineers and shipbuilders who can afford the means and opportunity. Yet there is a very great number of the young men who enter our workshops and factories to whom such a term of attendance and scale of fees are impracticable, and for whose special benefit other institutions with the leading feature of evening science classes have been arranged, and it is to these that the author begs more particularly to draw attention this evening.

We have Anderson's College, which is the oldest; next comes the Mechanics' Institution, which began its career in 1824; and then we have the more youthful Allen Glen's Institution, with its excellent well arranged day school for the training of boys prior to their entering the workshop, all doing good work.

The author thoroughly believes that science of magnetism and electricity will very soon hold an important place in every young engineer's education, for assuredly within a few years we shall be using electricity and magnetism as a means of transmitting power in our workshops and factories to drive special machines as well as

for lighting our public buildings and houses, and it will therefore be necessary for those in charge to know something of the laws which regulate and guide its action.

The three leading institutions for the instruction of young men following after or intending to prosecute one or other of the industrial arts, are, as we have pointed out, doing their best to instil a sound applied science education to those attending, and if the members of this Institution will only combine and favourably consider the remarks here made and advise their young men to take fuller advantage of the opportunities offered at these evening and day classes, he has every confidence in stating that considerable benefit will accrue to all parties concerned. He has to thank several of the well-known firms of engineers and shipbuilders for their kindness in allowing him and his students to visit their works, and not only have they been permitted to visit works, but tools, drawings, and appliances have been forwarded to his class-room for assisting him in the explanation of principles.

Amongst other places they did not forget to visit the Naval and Marine Exhibition together. And this leads him to start a point wherein he believes the technical institutions in Glasgow are sadly wanting.

It will not be every year that they can have a Naval and Marine Exhibition to visit, but why not have a central Industrial Museum in this large, busy, and wealthy city where the more expensive models and designs illustrative of practical mechanical and shipbuilding principles could be kept, and to which students with their teachers could have access.

It is impossible for any single institution to contain within itself all that is necessary in this way, not only on account of the expense, but from the space required for a more or less complete set of models and working diagrams.

At schools and colleges the workshop practice and art can never be completely taught. It is only the scientific principles and laws of nature which regulate an art or profession which can be accomplished, and if these are systematically and carefully explained and

made clear to a lad, there cannot be the slightest doubt but that a great deal of trouble to the young, as well as waste of time and material to the old, can be avoided.

The author most respectfully suggests the advisableness of this *the representative Institution of Engineers and Shipbuilders of Scotland* forming a committee to consider and foster the theoretical part of the technical education of the young and rising generation of engineers, shipbuilders, and artisans in this the second city of the kingdom; and would express the hope that such an Institution may see fit to lend its influence in promoting the objects which the author has had the privilege of laying before its members.

The PRESIDENT said that perhaps there was no subject at the present day that could engage our attention more advantageously than the education of our young men, and the proper way of going about it. He trusted that after the paper was printed and in their hands, they would carefully consider it, and be prepared to discuss it thoroughly at the next meeting. He proposed a vote of thanks to Principal Jamieson for coming before them and reading the paper.

The motion was carried unanimously.

The discussion of this paper took place on April 26th, 1881.

Mr DAVID ROWAN said the paper gave an interesting history of the experience of all who had passed through the workshop in their apprenticeship, and while perhaps the novice received some rather rough treatment, yet knowledge was imparted to him through it; and upon the whole he believed that in this respect matters remained very much the same as they were forty years ago. Employers of labour took no more to do with their apprentices now than they did then; and they did not in most cases know the name of a single one of them. It was an excellent paper, and drew attention in particular to two or three important points. First of all, as to how far it was the duty of employers to teach their apprentices. It had always been assumed, when engaging an apprentice, that the employer undertook to teach him the trade

which was to be the business of his life; in reality, however, he received no teaching, but was allowed to learn by his own observation and practice as he best could. He did not for a moment assume that the common usage of the workshop could be changed from what it had always been, but it would certainly be a relief to employers if some attempt were made by them to implement the condition of teaching. He thought employers had a great deal in their power. There were now several institutions in this city where technical information was given. He did not wish to make their workmen philosophers, but he wished to give them the means, if they had the ability, to gain useful information. The employer could exert influence on their youths to induce them to attend such institutions in the evening, especially those who were not in independent circumstances. Many of them were sons of working men, to whom the payment of fees might be a serious question. Now, there were some firms in the city who sent a certain number of young men to classes in the evening, and who received a quarterly report from the teacher as to how their protegés had conducted themselves, and what progress they had made. This excellent method might be adopted by every one who employed apprentices. It was remarkable how few of them attended the educational institutions of the city. He did not suppose that there were over 400 or 500 in training in these institutions who were engaged in the shipbuilding and engineering works of the city. He thought the employers of labour in these branches of business should meet and devise some scheme whereby they might endeavour to exercise a controlling influence over their young people, and see that they attend some evening classes. He did not think this matter required discussion, but he was of opinion that they should appoint a committee to seek to take steps to carry employers generally with them, and see how they could accomplish the end in view. This was a subject that he had long taken a deep interest in, and he still felt it difficult to get employers to take the slightest interest in their apprentices.

The PRESIDENT cordially endorsed every word that Mr Rowan had said, and he was also confident that a committee formed by this

institution might do considerable good among the employers of labour. He knew it was difficult to move some of them; but still he thought they might remit this matter to the Council to select a committee from the members of the Institution to take the matter up.

The suggestion was unanimously agreed to.

The Secretary read the following communication from Mr JAMES LYALL:—When this subject of Education was brought under the notice of the Institution on the 22nd November, 1870, by Professor John Young, the writer was at the meeting and took part in the discussion which followed its reading; and while trying to point out some of the workshop difficulties in the way of young men regularly attending classes for the purpose of acquiring the theoretical knowledge advocated and desirable, I "suggested that the members of this Institution open up their drawing offices to competition by the young men in their employ, and make it known to them. Include among the conditions of admittance regularity of attendance and propriety of conduct in the workshops, as well as ability to draw and pass examinations in arithmetic, &c.," while they are serving in the workshop; and I am convinced, by appreciative application, the great mass of the future men will be raised to a higher platform of usefulness, *many* of them will fill the foremost posts in their calling, and *all* will maintain the reputation of their employers, by enabling them to produce the best work at the most economic rates. Unless the young engineer, shipbuilder, or artisan knows of some special encouragement, such as I have indicated, to stimulate a general competition, I doubt whether the mere advice of any one over him would have the effect of a marked change for scientific pursuits at the close of a day or longer term of hard work. In short, if you would raise the young by self-application, you must first succeed in planting the hope of some prized object which he knows may become his before his view.

Mr ANDREW JAMIESON was very glad that the meeting had taken the practical view of the case indicated, and that they had so far supported the case he had set before them. He had received a letter

the previous day from Mr Denny, of Dumbarton, approving of the remarks in his paper, and suggesting that if a committee were appointed, it might draw up forms of examinations for young men engaged in engineering and other cognate branches. He (Mr Jamieson) hoped the movement they had initiated that evening would be productive of good.

Mr JOHN TURNBULL, Jun., exhibited and explained a new form of lubricator for steam engines.

The PRESIDENT in proposing a vote of thanks to Mr Turnbull, stated that Wilson's self-acting lubricator had had a most important bearing on the success of the double cylinder compound marine engine, great difficulty having been felt in keeping the valves in order previous to its introduction.

On Pistons, with a Description of a New Piston designed by Mr Wm. Rowan, Belfast.

By Mr JAMES HOWDEN.

(SEE PLATE IX.)

Received and Read 26th April, 1881.

IN making trial recently of various pistons with double-action springs and packing rings, I have had occasion to observe and study more particularly than hitherto the action of such springs and packing rings and to note their advantages or disadvantages, and other phenomena which arise in the working of the usual forms of pistons. As the ends to be aimed at in the construction of pistons are that they shall work steam-tight and at same time practically frictionless, the closer observation to which I have referred has led me to the conclusion that hitherto they have been constructed without due regard to the conditions which are absolutely necessary to secure these essential qualities. This conviction has been very much confirmed by studying the construction and working of a piston which as yet must be new to most of the members of this Institution. This piston to which I refer is the invention of Mr Wm. Rowan, of Belfast, an engineer of great ability and well known to the larger steam power owners all over Ireland, as for many years the managing partner of the York Street Foundry, Belfast, a large engineering establishment founded by his father, the late Mr John Rowan.

I shall describe this piston of Mr Rowan's in the latter part of my paper, and meanwhile propose to make some remarks on the construction and action of pistons generally.

The actual loss of steam and of power in our best steam engines from the leakiness and friction of their pistons is, I am convinced, very greatly underestimated. The object of my paper is to direct attention to the causes of this loss, and to show it is possible to construct pistons free from these prevailing defects.

Let me first refer to the quality of steam-tightness.

Absolute steam-tightness in a piston at work is what I may safely assert very seldom occurs. It is much more difficult to secure than is generally supposed. Rarely, indeed, is a piston made that can possibly be steam-tight to begin with, and the possibility of leakiness exists at many points. Probably steam-tightness has never existed in any piston with a single packing ring after it has worked a short time, even though the piston has been perfectly steam-tight at first starting. On removing the junk ring of any such piston after it has worked for some time, evidences of steam having passed between the faces of the packing ring and junk ring or piston flange into the interior space are quite apparent. The scraped or ground faces are in places dull and steam worn, and if oil or grease has been used to lubricate the cylinder, grease and dirt will be found in the space inside of the packing ring. It is a matter of common experience that the packing ring after a time gets slack between the junk ring and piston flange, and the junk ring must be frequently refitted to the body of the piston and packing ring to keep the piston even moderately tight.

This slackness is, no doubt, caused by the junk ring and piston flange in the constant reciprocation of the piston giving alternately a pull or tug to the packing ring, in overcoming its friction against the walls of the cylinder, and in starting it on its travel in the opposite direction. This pull on the faces of the packing ring after several thousands—it may be millions—of repetitions, compresses the metal and produces a slackness of the ring between the two faces of the piston, and allows it to pass steam on its admission at the end of each stroke into the interior space. It is important to notice that the greater the tightness of the packing ring against the cylinder the greater must be the pull on the ring, and the

sooner will this leakage begin in a piston originally steam-tight. This leakage over the faces of the packing ring is not only more common than leakage between the packing ring and cylinder, but also, for the same quantity, much more objectionable, as it increases the friction of the packing ring against the cylinder by adding the pressure of the steam on its inside surface to that of the springs.

In pistons with double packing rings this leakage over their end faces is sought to be overcome by a pressure endwise from a spring which presses the packing rings at same time outwards towards the walls of the cylinder. I find, however, that where one spring is employed for this double action, it necessarily gives the packing rings a greater pressure outwards against the cylinder than endwise against the piston faces, so that before a sufficient pressure endwise is attained the pressure outward becomes much too great. This causes undue friction and wear of the cylinder and packing rings; and where there is much wear there will soon necessarily be leakage through the packing rings and interior of the piston. The dirt and grease often so plentifully found inside the packing rings, show that steam has been passing about as freely to the inside of the piston, as into the cylinder itself. I would also notice here that the pressure of the packing rings endwise against the junk ring and piston flange should be considerable, and sufficient to withstand this friction against the cylinder, while the pressure of these rings against the cylinder should be light.

From the causes I have stated, it therefore appears to me evident that pistons with single, or with double packing rings of the kind I have mentioned, have within themselves the conditions of such wear as will produce leakage after a short period of work, however tight they may be on first starting.

Locomotive and similar pistons with Ramsbottom rings, or with larger cast-iron packing rings sprung into the recess or recesses turned out of the piston body, never approach tightness. They pass steam freely from the first, at least at the cut of the rings, if not all round, and in consequence great friction is set up by the pressure of the steam on the inside of the rings, which wears both

rings and cylinder very quickly. The loss from this friction and the piston leakage in locomotive engines is undoubtedly very great, and some of its effects I will refer to afterwards when treating of the element of friction.

In ordinary pistons with junk rings there are several points beside the faces of the packing rings where leaks take place. The covering pieces over the cut in the packing rings are very seldom of a character to ensure steam-tightness with steam of the pressure of the present day, and quite as seldom is the workmanship sufficient for this purpose. The practice of using brass nuts in the body of the piston to secure the junk ring is also a common source of leakage. Among the number by which the junk ring of an ordinary sized piston is held, several of them will, as a rule, be found to pass steam through to the inside of the piston. This mode of fastening, which may be desirable for pistons with single packing rings when the junk ring requires to be refitted to the body of the piston, is quite unnecessary with double packing rings, and should never be used if it is desired to avoid risk of leakage.

When we consider how difficult it is to make a bolted joint tight under a high pressure, even with broad faces and jointing material between, it will be seen that nothing but the most perfect workmanship will succeed in making a piston tight all over when working with high pressure steam; and I cannot but express my opinion that in comparison with the vital importance of a thoroughly steam-tight piston, far too little consideration is given to its construction.

I come now to the question of friction in the working of pistons. The element of friction is an important one, and a piston at once steam-tight and practically frictionless possesses a value which it would be difficult to over-estimate. There cannot, of course, be an entire absence of friction, but it may be reduced to the least possible extent. The piston of a well-made indicator is an example of a piston steam-tight under any usual pressure, and practically frictionless. It works without any pressure outwards against the walls of the cylinder. In pistons with packing rings

and compensating springs, one of their greatest defects is the universal excess of pressure outwards against the cylinder. I believe that the amount and injurious effect of this pressure is very much underrated. It is generally supposed that when a cylinder is found smooth and polished, that the piston is working with very little friction. This is often a delusive inference, for in a well-lubricated cylinder the packing rings, if bearing fairly all round, will make a smooth skin on the cylinder, even under a strong pressure against it.

In pistons with single packing rings kept against the cylinder by a number of detached springs, the effect of these springs is generally very unequal, some giving much more pressure than the others. When one loses its elasticity or breaks, the packing ring not only loses the effect of this spring outwards, it is also pulled off the cylinder by the spring on the opposite side, which has then become unbalanced. This causes an increase of friction on one side of the cylinder by the packing ring, while on the other side steam may be passing freely between it and the cylinder. The effect of this unequal pressure is to wear the cylinder unequally, as will be found in almost every case in which a piston with a packing ring pressed outwards by a number of detached springs is used.

In pistons with double packing rings and a continuous spring, this irregularity of pressure outwards by the packing rings is avoided. There is, however, in all pistons with double packing rings in which the pressure outwards and endwise is given by the same spring, necessarily a much greater pressure outward than endwise. This arises from the fact that when the pressure by the junk ring in screwing down is brought on the packing rings in contact with the spring, the packing rings continue to move outwards until they come hard against the cylinder; and not until then does the pressure begin endwise against the junk ring and piston faces, and any increase thereof is merely the effect of the reaction from additional pressure on the cylinder walls. As precisely the opposite effect is essential in a properly constructed piston—strong pressure endwise and light pressure outwards—a serious construc-

tional defect therefore exists in all pistons of this class. If they are made with sufficient pressure endwise to prevent leakage over the ends of the packing rings, the pressure against the cylinder will be much too great; and if, on the other hand, the pressure outwards is reduced to give only sufficient to prevent steam passing between the packing rings and cylinder, it will be insufficient endwise, and allow steam to pass over the ends of the rings at the beginning of each stroke. I have in a good many instances found the wear of the cylinders to be much more rapid from pistons with double packing rings than I have ever observed it with single packing rings. It is no doubt attributable to the power of pressing the packing rings outwards by the junk rings.

I have already referred to the effects of leakage in causing an increase of the friction of the packing rings against the cylinder. The effect of this increased friction is to increase the leakage, not between the packing rings and cylinder walls, but through the piston itself, and this increased friction from the leakage will be found to wear the cylinder quickly, especially at the ends.

A few figures will give a more definite idea of what this increased pressure and friction of the packing rings on the cylinder from leakage may amount to. Take a high pressure cylinder 52 inches diameter, with packing rings 5½ inches in depth, and working steam pressure 70 lbs. If we suppose the packing rings to leak over their faces sufficiently to allow a pressure of 40 lbs. to accumulate inside at the end of each stroke, this pressure, on the inside of these rings, with an area of about 850 square inches, aggregates fully 15 tons, in addition to that caused by the springs. The wear from this increased pressure is soon apparent on the cylinder, especially at the ends, where the pressure of steam is greatest.

In locomotive engines the effect is very distinctly seen. All locomotives' cylinders wear wide at the ends, and the packing rings wear very quickly away. This rapid wear arises from the steam getting inside the packing rings on its admission at each end of the stroke. The great pressure forces the packing ring or rings against the cylinder and produces a correspondingly great friction. As the

pressure of the steam rapidly diminishes as the piston travels along the cylinder, the friction and wear caused by the pressure of the steam on the rings likewise diminish, hence the cylinder is less worn in the middle than at the ends.

The wear of the packing rings of locomotives is so great from the cause I have mentioned, that I understand the London and North-Western Railway Company renew them in their passenger engines every three months. The cylinders also require re-boring at stated periods. The loss of steam and of power in locomotive engines from leaky pistons. and the consequent friction, must be so great that if prevented, the saving of coal and wear and tear of machinery must be sufficient to affect beneficially the dividends of any railway company.

Those who have used Ramsbottom rings will have noticed that if they do not become fixed hard and fast in their grooves by dirt they very quickly wear quite away. This is not caused by their own spring outwards against the cylinder, but entirely by the pressure of the steam getting inside and forcing them against the cylinder, as I have above explained.

These facts to which I have called attention point to the conclusion that hitherto pistons have been very defective in the two essential qualities of steam-tightness and absence of friction, and that a serious waste of power must arise therefrom. If, therefore, a piston can be made with certainty to work steam-tight for years, and with almost no perceptible wear, it must be considered as one of the most valuable improvements in the steam engine of the present day. I have much satisfaction in saying that these valuable properties are possessed by the piston of Mr William Rowan I am about to describe.

This piston was first described to me about fifteen months ago by Mr Robert Beath, C.E., Belfast, who had then had them at work, in the S.S. "Voltaic" of that port, for a year or more, with very marked results. The revolutions had been increased, vacuum improved, engines more easily handled, and for the first time they had, on removing the junk ring after a considerable period

in a true circle, is laid inside the loose packing ring, it forces the packing ring open at the cut a little, as shown.

The pressure of the spring is now brought to bear on the packing ring by drawing it in to the diameter of the cylinder, and bringing the ends where cut close together. As the spring hoop with its ends butting in the sleeve cannot be compressed, it is forced to accommodate its full length in the reduced diameter of the packing ring, by bulging into the several spaces between the projections on the inside of the packing ring, as shown in Figs. 2 and 6. In this simple way and by these simple means, a pressure extremely great or delicately light may be put on the packing rings at pleasure, with the utmost accuracy and certainty. It will be observed that the screwing down of the junk ring only affects the flat spring and the endwise pressure; it has no effect whatever on the vertical spring or outward pressure.

Mr Rowan has, after several years practice and study, and with the aid of a number of ingenious appliances, ascertained with great nicety, the proper dimensions and kind of hoop steel required for any diameter of piston, the height and length of the waves for the flat springs, and the length required for the vertical spring in any particular case, to give the required pressure outwards, when the packing ring is drawn home to the diameter of the cylinder.

As the invaluable properties of this piston would be lost if not accompanied by the most perfect workmanship in every detail, Mr Rowan has been very careful to have all the faces accurately ground steam-tight, a thing which I believe is seldom accomplished in any of our workshops, and the slip pieces covering the cut of the packing rings properly fitted, also the junk ring fastenings made so as not to pass steam.

A piston made in this careful manner, on this system—which appears to me to be the only one that can be called theoretically and practically correct—can therefore be put into a cylinder perfectly steam-tight and nearly frictionless, and the pressure against the cylinder definitely known, which contrasts strikingly with the rough haphazard manner in which other pistons are now set to work,

with which it is even impossible to obtain, if desired, the proper conditions for faultless working.

The application of the principle to ordinary locomotive pistons without a junk ring is a fact of very great importance. This, though at first sight apparently difficult, has been done with perfect success, so that locomotive engines which have one and all been working hitherto with leaky and wasteful pistons, and with much wear and tear arising therefrom, can now be fitted with pistons steam-tight, which will work for years with the slightest possible friction and wear, and without causing the unequal wear of cylinders which now universally prevails.

Figs. 4, 5, and 6 represent a locomotive piston as fitted by Mr Rowan to the engines of the Belfast and County Down Railway, where they are running with the most favourable results.

The valuable qualities possessed by this piston have now been amply proved by severe practical tests, extending over several years' duration. Some of them have been working for three years, and they have been equally successful in factories, steamships, and locomotives. In the Belfast, and Northern Counties Railway a locomotive has been running for about two and a half years with these pistons. They were examined lately and were found to have worn so slightly that it is probable they will have to run another equal period before it can be seen how long they will endure. In this engine the new pistons were fitted into cylinders partly worn by ordinary packing rings and were not rebored.

Contrasting this with the fact of the London and North Western Railway engines having their packing rings renewed every three months, the value of the "Rowan" piston becomes apparent. I saw myself, a few months ago, pistons taken from a locomotive of the Belfast and County Down Railway for examination after they had run several months. The cylinders had been rebored for the new pistons. There were no perceptible signs of wear on the rings. The tool marks were actually still visible at some parts.

I will only mention further the case of a factory engine in which one of Mr Rowan's pistons was tried against one of Mather & Platt's,

evidently constructed in a very superior manner, and carefully kept. After the consumption and power of the engine had been tested over a period in a very exhaustive and thorough manner, the Mather & Platt piston was drawn from the cylinder in beautiful condition, the cylinder being polished like a looking-glass. There had evidently been little or no escape of steam going on. When the "Rowan" rings and springs were fitted in the same piston body, the power and consumption of the engine were taken as carefully as before, and over a similar period of time. The result was found to be 9 per cent. saving in favour of the "Rowan" system. From the apparently perfect condition of the other piston, I attribute this saving solely to the reduced friction from the "Rowan" packing rings.

With these facts before you, and the description I have given, you will be able to judge somewhat of the merits of this new piston, and I trust your time has not been spent altogether unprofitably in the consideration of the working of pistons generally.

The discussion of this paper was postponed till the opening meeting of next session.

A Description of Wilson's Gas Producer for Firing Furnaces, with some Applications.

By Mr F. J. ROWAN, C.E.

(SEE PLATE IX.)

Received and Read 26th April, 1881.

THE Wilson Gas Producer, which is illustrated by the model and diagrams shown, is a closed furnace for decomposing coal and producing from all its component parts, including the coke or fixed carbon (but, of course, excluding the ash) combustible gas, which may subsequently be used in heating furnaces situated either quite near or at some distance away.

This new gas producer has, in fact, the same functions as the Siemens gas producer, which is well known, but its sphere of usefulness is much larger than Siemens' for the following, among other reasons.

In the first place, for a given amount of work done in a given time its cost is only one half of that of the former arrangement, and it occupies only half the space. It also makes good gas from inferior and slack coal, and the gas is delivered at a positive pressure. There is therefore no need to cool the gas in order to purify it or to get a draught on the producer.

The producer is by preference (but not of necessity) of a cylindrical form, of dimensions varying from about 6 to 10 feet in height, and about 4 to 8 feet in diameter; having a wrought-iron shell or casing of $\frac{1}{4}$ inch plates (A), inside which there are linings of red brick (B) and of fire-brick (C), to give the required internal

contour and to form the annular space (D) at the top, where the gas collects, and from which it is led away by a branch pipe (E). There is a solid hearth which has a ridge (F) across the centre, formed by the central tuyere casting (G) and its fire-brick covering (H), and a door on each side (I and J), at the end of this ridge, gives facility for cleaning out ashes and clinkers from the whole area of the hearth. Opposite to these doors are two vertical tapered pipes (K and L), through which air is forced into the central tuyere (G) by a jet of steam in each; and there are poking holes (M) in the sides of the producer and on the top, and also "crupper" doors (N) provided for the insertion of temporary bars to support the burden of fuel when the ashes, &c., are being cleaned out. The coal is fed into the producer by means of the hopper and bell cone arrangement (shown at O).

The action of the producer may be briefly described as follows:— The interior is nearly full, from top to bottom, of coal which rests on the solid hearth, there being no grate bars. Into the centre of this mass of fuel, near the bottom and as far as possible from the side walls, air is injected from each side of the central tuyere. The air is forced in by two small steam jets. A rapid combustion takes place above the tuyere where the carbon is decomposed to carbonic oxide at a bright red heat, and this gas ascends and passes out at the ports into the annular flue which surrounds the top portion of the chamber.

The coal is charged from time to time through the bell and hopper at the top, and the hydrocarbons are for the most part distilled in the retort portion, which is above the ports, and have to pass downwards to escape along with the carbonic oxide. The top portion of fuel is comparatively cool, because the hot gases from the bottom do not pass through it (as in Siemens' producer), and hence the distillation of the hydrocarbons is gradual and uniform, no great "flushes" of gas occurring just at the moment of charging. This conduces to great regularity in the production of gas, and it has the further advantage of causing the heavy hydrocarbons, or tarry gases, to pass down through a hotter portion of the charge on their way

out. Analysis of the resulting gas shows that by this means they are for the most part decomposed into the lighter hydrocarbons, and into carbonic oxide and hydrogen, and are thus made serviceable for heating.

The comparatively small first cost and small space necessary for the establishment of this gas producer, coupled with the advantages of delivering the gas hot and under a positive pressure, have accelerated its adoption in many instances where the more cumbrous and costly arrangements hitherto generally used were considered inadmissible. Thus, the great advantages of heating by gas are obtained for purposes of a very varied character, and these advantages are now further developed by newly designed methods of application not before in practical use.

The producer is used for working Siemens' regenerative furnaces for melting steel and glass on the open hearth and in pots, and for other purposes where brick regenerators are used on the reversing current system. The original form of Siemens' producer has not been much used except for obtaining high heats in regenerative furnaces, but the Wilson producer has been introduced in many cases without any regeneration, and it is used in this manner for heating copper and iron plates; annealing steel castings and iron, steel, brass, and copper wire; also for heating core-drying stoves and moulds in foundries; for some chemical operations, and for firing steam boilers.

Some most interesting applications of gas firing have been made by means of this producer, to furnaces worked on the "blow-pipe" system. This is a system introduced by Mr Wilson in which the blow-pipe flame is produced on the large scale in furnaces and on hearths, and very satisfactory results have thus been obtained in the direction of obtaining very high heats by simple means.

The producer is applied in this way for welding wrought iron tubes, and has been at work for some time on the same system for working pottery muffles. This system also offers unusual facilities for carrying out various operations in boiler-making, and advantage has been taken of these in an excellent series of furnaces designed

for these purposes by Mr Wilson. A very simple smith's hearth, which of course rescues the iron from contamination by the coal, cinders, or ash, has been designed on the same plan.

The blow-pipe gives an intense local temperature—say for a distance of from 10 to 15 feet—but as those who are acquainted with the use of gas are aware, it is possible to get an extremely long gas flame, and the Wilson producer is working furnaces upwards of 50 feet in length, both for metallurgical and for chemical operations, a uniform heat being maintained throughout the whole length.

The application of gas to boiler firing is a matter of great interest, and it is satisfactory to know that in this department also, this producer has been successfully introduced. It answers so well for this purpose and is so effectual a preventive of smoke that it will in all probability be largely adopted. At present no experiments have been made as regards economy in raising steam by its use, but as the commonest qualities of fuel may be used, and perfect and continuous combustion secured, the application contains all the elements for obtaining a perfect result.

The gas producers may be situated either close to or at any distance from the furnaces or boilers to be fired. There is little radiation from the producers, and consequently no danger and little loss of heat from this cause, and the gas is carried either in overhead mains of wrought iron lined with fire brick, or preferably in an under-ground culvert. It will be understood that the gas is not in a state of ignition in the conducting flue, but is lighted like town's gas at the point where a development of heat is required, as at the front end of a boiler flue. The draught of a chimney can pull in the necessary air which mixes with the gas at that point, the quantity of air and of gas being regulated by valves.

The perfect facility with which the proportions of gas and air may be regulated constitutes for many metallurgical and chemical purposes one of the most valuable points of superiority of this system over ordinary coal firing. A reducing or an oxidizing flame may be maintained at will with constant regularity, whereas with a grate and ordinary firing this is impossible.

Mr WILSON, the inventor of the apparatus, in answer to the President, explained that as the gas producer could be placed entirely above the ground line, no excavation was necessary; and as the structure was of a stable and self-contained form, it might be placed on a comparatively bad foundation. For raising steam it had only been applied to a limited extent as yet, and there had therefore not been an opportunity to compile figures showing the economy of the system as applied to boilers under different circumstances; but as it was smokeless, and perfect combustion was insured, there were the elements present for securing a perfect result. The radiation of heat from the gas producer itself was very small, and the temperature of the gas on leaving the producer was 700 to 800 degrees Fahrenheit. At present there were none of these producers at work in the Glasgow district. The gas contained about 40 per cent. of combustible, the remainder being nitrogen.

Mr MAYER asked whether or not there was any instance of the gas itself being stored in gas holders so as to be turned to account at the proper time, and whether these gas producers might not be generating gas at a time when there was no special outlet for it, but which might afterwards be utilised. He might mention the case of a gentleman largely engaged in the fire-brick manufacture, who had gone into the adoption of this gas producer on a large scale, and was so satisfied of its value that he had determined to turn it to account in the making of bricks by the use of a gas kiln. He intended to have his furnaces so arranged as to use the gas in drying and burning his bricks.

Mr WILSON remarked, in reply, that he had not heard of any attempt being made to store this gas in holders. The quantity was so great, and its production could be so easily regulated to the requirements of the furnaces, that storing in gas holders seemed to be unnecessary.

The PRESIDENT said that no doubt heating by gas was coming rapidly into notice. Mr Siemens had considered he had got a good principle of furnace, but Mr Wilson considered that his furnace was superior to it; and if it proved to have the advantages indicated it

was sure to work its way to the front. They were all indebted to Mr Rowan for drawing their attention to it, and to Mr Wilson for his explanations. He moved that a vote of thanks be passed to both gentlemen.

The vote was unanimously agreed to.

Lectureship on Naval Architecture and Marine Engineering in the University of Glasgow.

The PRESIDENT gave the history of the movement, said Mr J. G. Lawrie had kindly consented to deliver lectures during first session gratuitously, and trusted that the Institution would unanimously give the scheme its moral support and influence, so that the University authorities might know that the Institution was in earnest in this work. It had been before the Council on two different occasions, and they had referred it to this meeting.

Mr GALE referred to what Mr D. Rowan had done in the matter a good many years ago.

Mr ROBERT DUNCAN stated how heartily he had been working to establish this lectureship, gave Mr Lawrie much credit for the generous offer he had made, and said that nothing should be allowed to prevent this scheme being established on a sound and lasting basis. He moved—

"That this Institution now agree to give the proposed Lectureship all the moral support desired."

Mr JAMES REID seconded the motion, and said it required no words from him to encourage the Institution to pursue this object to a successful end.

The motion was carried unanimously.

Mr H. R. ROBSON drew attention to the fact that the Institution had no funds that could be used for assisting to endow such a chair, and suggested that funds be raised to help to endow the Lectureship, and that a committee be appointed to carry it out.

It was then remitted to the Council to appoint a committee.

Institution of Engineers and Shipbuilders

IN SCOTLAND

(INCORPORATED).

TWENTY-FOURTH SESSION, 1880-81.

MINUTES OF PROCEEDINGS.

THE FIRST GENERAL MEETING of the TWENTY-FOURTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 2nd November, 1880, at 7·30 P.M.

Mr JOHN L. K. JAMIESON, President, in the Chair.

The Minutes of Annual General Meeting of 27th April, and of Special Meeting of 18th May, 1880, were read and approved, and were signed by the Past-President, Mr ROBERT MANSEL, as the Chairman of these Meetings.

The President delivered his Inaugural Address, and, on the motion of Mr DAVID ROWAN, a cordial vote of thanks was awarded the President for his address.

Mr RALPH H. TWEDDELL read his Paper on "The Application of Hydraulic Pressure to Machine Tools." After some remarks from Members, it was agreed to adjourn the discussion of the subject till next General Meeting.

On the motion of the President, a vote of thanks was awarded Mr TWEDDELL for his Paper.

The President announced that the Candidates balloted for had been elected, the names of these gentlemen being as follows:—

AS A LIFE MEMBER:—

THOMAS ORMISTON, C.I.E., Civil Engineer, London.

AS MEMBERS:—

ALFRED GEORGE BERRY, Mechanical Engineer, Glasgow.
JAMES CLARKSON, Mechanical Engineer, Maryhill.
SAMSON FOX, Engineer, Leeds.
WILLIAM HENDERSON, Civil Engineer, Dumfries.
CHAS. PULLAR HOGG, Civil Engineer, Glasgow.
LAWRENCE NIVEN JACKSON, Mechanical Engineer, Ceylon.
JAMES W. MACFARLANE, Ironfounder, Maryhill.
JAMES M. PEARSON, Civil Engineer, Kilmarnock.
ALEXANDER SMITH, Mechanical Engineer, Glasgow.
RALPH HART TWEDDELL, Mechanical Engineer, London.
ALEX. WOOD, Mechanical Engineer, Glasgow.

AS ASSOCIATES:—

GEORGE M'CALLUM, Ship Carpenter, Glasgow.
JOHN STEEDMAN, Life Buoy Maker, Glasgow.

AS GRADUATES:—

JAMES AITKEN, Apprentice Mechanical Engineer, Crosshill.
GEORGE C. DOUGLAS, Draughtsman, Glasgow.
BRUCE HARMAN, Draughtsman, Glasgow.
L. P. JOHNSON, Apprentice Engineer, Glasgow.
JOHN KYLE, Pupil Civil Engineer, Glasgow.
PATRICK F. M'CALLUM, Draughtsman, Motherwell.
ROBT. MACLAREN, Jun., Student Engineer, Glasgow.
IVAN MAVOR, Apprentice Shipbuilder, Pollokshields.
MATTHEW RANKINE, Apprentice Engineer, Glasgow.

THE SECOND GENERAL MEETING of the TWENTY-FOURTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 23rd November, 1880, at 7·30 P.M.

Mr JOHN L. K. JAMIESON, President, in the Chair.

The Minute of General Meeting of 2nd November, 1880, was read and approved, and signed by the President.

The Discussion of Mr Ralph H. Tweddell's Paper on "The Application of Hydraulic Pressure to Machine Tools" was proceeded with and terminated, and on the motion of the President, a vote of thanks was awarded Mr Tweddell for his additional remarks prior to the opening of the discussion.

A Paper by Mr JOHN HASTIE, on "Screw Nuts with Differential Threads, and some Applications of same," was read; a discussion followed, and was continued to next General Meeting. On the motion of the President, a vote of thanks was awarded Mr Hastie for his Paper.

The President announced that the Candidates balloted for had been elected, the names of these gentlemen being as follows:—

AS A MEMBER:—

THOMAS ANDERSON, Mechanical Engineer, Bombay.

AS GRADUATES:—

JAMES M. CROOM, Engine Draughtsman, Glasgow.
GEORGE THOMSON, Apprentice Draughtsman, Motherwell.

THE THIRD GENERAL MEETING of the TWENTY-FOURTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 21st December, 1880, at 7.30 P.M.

Mr J. L. K. JAMIESON, President, in the Chair.

The Minute of General Meeting of 23rd November, 1880, was read and approved, and signed by the President.

The Discussion of Mr JOHN HASTIE'S Paper on "Screw Nuts with Differential Threads, and some Applications of same," was proceeded with and terminated.

A Paper by Mr THOMAS E. RAWLINSON, on "Screw Shafting," was read.

Mr W. J. MILLAR read his Paper on "Early Clyde Built Steamers." A Discussion followed and was continued to next General Meeting.

The President announced that the Candidates balloted for had been elected, the names of these gentlemen being as follows :—

AS MEMBERS :—

WILLIAM BROWN, Mechanical Engineer, Glasgow.
JAMES W. BURNS, Superintendent Engineer, Glasgow.
ALEXANDER CAMPBELL, Jun., Engineer, Glasgow.

AS AN ASSOCIATE :—

JOHN CASSELLS, Manufacturer, Glasgow.

AS GRADUATES :—

SINCLAIR COUPER, Draughtsman, Coatbridge.
HENRY M. FELLOWS, Apprentice Engineer, Glasgow.
ROBERT FULTON, Draughtsman, Glasgow.
DUNCAN HOUSTON, Draughtsman, Glasgow.
STANLEY TATHAM, Draughtsman, Glasgow.

THE FOURTH GENERAL MEETING of the TWENTY-FOURTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 25th January, 1881, at 7.30 P.M.

Mr J. L. K. JAMIESON, President, in the Chair.

The Minute of General Meeting of 21st December, 1880, was read and approved, and signed by the President.

The Discussion of Mr W. J. MILLAR'S Paper on "Early Clyde Built Steamers" was continued, and it was agreed to keep the subject open so that Members, and others, might have further opportunity of contributing matter of importance, and that thereafter a Committee be appointed to adjust the whole with the view of placing on the Transactions as complete and accurate a record as now attainable of the Early Clyde Steamers.

Mr C. C. LINDSAY read his Paper on "The Corrosion and Preservation of Iron and Steel." A vote of thanks was awarded Mr LINDSAY for his Paper, and the Discussion adjourned to next General Meeting.

The President announced that the Candidates balloted for had been elected, the names of these gentlemen being as follows :—

AS MEMBERS :—

ROBERT DUNCAN, Mechanical Engineer, Glasgow.
WILLIAM HALL, Jun., Shipbuilder, Aberdeen.
JAMES HUNTER, Mechanical Engineer, Aberdeen.
HENRY M. NAPIER, Shipbuilder, Yoker.
CHARLES REID, Civil Engineer, Kilmarnock.
JOHN SCOTT, Mechanical Engineer, Aberdeen.
WALTER STODDART, Supt. of Way and Works, Carstairs.

AS GRADUATES :—

MATTHEW TAYLOR BROWN, Assistant Engineer, Pollokshields.
STEPHEN HANDS, Apprentice Engineer, Glasgow.
A. CAMPBELL HOLMS, Apprentice Shipbuilder, Partick.
ERNEST W. MOIR, Apprentice Engineer, Glasgow.
WILLIAM STEVENSON, Engineer's Draughtsman, Glasgow.

THE FIFTH GENERAL MEETING of the TWENTY-FOURTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 22nd February, 1881, at 7.30 P.M.

Mr J. L. K. JAMIESON, President, in the Chair.

The Minute of General Meeting of 25th January, 1881, was read and approved and signed by the President.

The Discussion of Mr W. J. MILLAR'S Paper on "Early Clyde Built Steamers," was continued, and additional information contributed by Members, by letter and otherwise.

The Discussion of Mr C. C. LINDSAY'S Paper on "The Corrosion and Preservation of Iron and Steel," took place and was terminated.

The following Papers were read:—

On "Strengthening Malleable Iron by Breaking it and by Compressing it;" by Mr THOS. DAVISON.

On "Steel Castings;" by Mr FRANK W. DICK.

On "A Water Meter and Hydraulic Motor;" by Mr DAVID JOHNSTON. Votes of thanks were awarded to the authors of these Papers, and the Discussions were adjourned to next General Meeting.

The President announced that the Candidates balloted for had been elected, the names of these gentlemen being as follows:—

AS A MEMBER:—

JOSEPH RUSSELL, Shipbuilder, Port-Glasgow.

AS GRADUATES:—

WILLIAM FERGUSON, Apprentice Engineer, Partick.
JAMES HARVEY, Apprentice Engineer, Glasgow.
SAMUEL B. NEWTON, Apprentice Engineer, Glasgow.

THE SIXTH GENERAL MEETING of the TWENTY-FOURTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 22nd March, 1881, at 7-30 P.M.

Mr J. L. K. JAMIESON, President, in the Chair.

The Minute of General Meeting of 22nd February, 1881, was read and approved, and signed by the President.

Mr ANDREW MACLEAN and Mr DAVID KINGHORN were appointed Auditors of Annual Accounts for present Session.

The Discussions of the following Papers took place and were terminated:—

On "Strengthening Malleable Iron by Breaking it and by Compressing it;" by Mr THOS. DAVISON.

On "Steel Castings;" by Mr FRANK W. DICK.

On "A Water Meter and Hydraulic Motor;" by Mr DAVID JOHNSTON.

Mr ANDREW JAMIESON, C.E., Principal, Glasgow Mechanics' Institution, read his Paper on "The Technical Education of our Young Engineers, Shipbuilders, and Artizans," the Discussion of which was adjourned to next General Meeting.

Mr JOHN TURNBULL, Jun., exhibited and explained a New Form of Lubricator for Steam Engines. A vote of thanks was awarded Mr TURNBULL.

The President announced that the Candidates balloted for had been elected, the names of these gentlemen being as follows:—

AS MEMBERS:—

GEO. H. BAXTER, Engineer Manager, Leith.

THOMAS BURT, Engineer and Founder, Glasgow.

WM. CROCKATT, Mechanical Engineer, Glasgow.

WM. A. MACKIE, Ship Draughtsman, Glasgow.

WILLIAM MENZIES, Superintendent Engineer, Newcastle-on-Tyne.

AS GRADUATES:—

D. DAVIDSON, Assistant Civil Engineer, Glasgow.

ROBT. WATSON, Apprentice Engineer, Glasgow.

THE ANNUAL GENERAL MEETING of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 26th April, 1881, at 7·30 P.M.

Mr J. L. K. JAMIESON, President, in the Chair.

The Minute of General Meeting of 22nd March, 1881, was read and approved, and signed by the President.

The Treasurer's Annual Financial Statement, duly audited, was laid before the meeting and received.

The PRESIDENT intimated that the Council had only been able to recommend the award of the Institution Medal for Papers read Session 1879-80.

The Institution Medal was then unanimously awarded to Mr John Thomson, for his Paper "On the St. Petersburg Water Works."

The Election of Office-Bearers to fill up vacancies caused by retiring Members of Council then took place. Mr JAMES REID and Mr JOHN HENDERSON, Jun., were unanimously elected Vice-Presidents; and the following gentlemen, by a majority of votes, were elected as Councillors:—Messrs ROBERT DUNCAN, JAMES GILCHRIST, C. R. HARVEY, W. R. WATSON, and ROBERT DUNDAS.

The PRESIDENT read statement as to proposed Lectures on Naval Architecture and Marine Engineering in the Glasgow University, which had been discussed and approved by the Council, and was now submitted for the consideration of the General Meeting. The President pointed out that all that the Institution could do as a body was to give the movement its moral support and influence.

Mr ROBERT DUNCAN then moved "That the Institution now agree to give the proposed Lectureship all the moral support desired."

Mr JAMES REID seconded the motion, which was unanimously agreed to.

On the suggestion of Mr H. R. ROBSON, it was remitted to the Council to appoint a Committee with the view of raising funds to endow the Lectureship.

The Discussion of Mr ANDREW JAMIESON'S Paper "On the Technical Education of our Young Engineers, Shipbuilders, and Artizans," was proceeded with and terminated, and a vote of thanks awarded Mr Jamieson for his Paper.

On the suggestion of Mr DAVID ROWAN, it was remitted to the Council to form a Committee to assist in advancing the objects aimed at in the Paper.

Mr JAMES HOWDEN read his Paper "On Pistons," the discussion of which was deferred to opening meeting of next Session.

Mr F. J. ROWAN described Wilson's Gas Producer. After some remarks, the further discussion of this subject was adjourned to opening meeting of next Session.

A vote of thanks was awarded Mr WILSON for being present and exhibiting the model of the apparatus.

The PRESIDENT announced that Mr HUGH MACMILLAN, Mechanical Draughtsman, Glasgow, had been unanimously elected a Graduate of the Institution.

TREASURER'S STATEMENT—1880-81.

GENERAL FUND.

Dr.				Cr.			
To Balance in Union Bank at close of Session 1879-80,			£153 17 6	*By* Rent of Old Rooms for half-year ending Whitsunday, 1880, ...	£50 0 0		
Subscriptions received:				Less Tax deducted, ...	2 1 8		
Session 1880-81, ...	£535 10 0					£47 18 4	
Arrears of Previous Sessions,	80 10 0			Interest on Bond on New Buildings for half-year ending Martinmas, 1880,	£33 15 0		
	£616 0 0			Less Tax deducted, ...	0 16 11		
Deduct Entry Money transferred to Building Fund, ..	16 10 0					32 18 1	
		599 10 0		Printing, ...		186 4 3	
Sales of Transactions, ...		1 9 6		Lithography, ...		200 19 0	
Bank Interest, ...		1 11 7		Salary to Secretary, ...		100 0 0	
				Commission Collection of Arrears of Subscriptions, viz. :—			
				For Session 1880-81, ...	£313 10 0		
				For Previous Sessions, ...	80 10 0		
					£394 0 0 at 5 °/₀	19 14 0	
				Salary to Sub-Librarian, for half-year ending 30th September, 1880, ...		12 10 0	
				Binding Books for Library, ...		4 0 0	
				Postages, ...		35 8 7	
				Delivery of Annual Volumes, ...		2 12 1	
				Gas, Cleaning, &c., ...		4 5 3	
				Stationery, &c., ...		7 2 4	
				Petty Cash, ...		3 19 1	
				Balance in Union Bank, ...		98 17 7	
		£756 8 7				£756 8 7	

DR. MARINE ENGINEERING MEDAL FUND. CR.

To Balance in Union Bank at close of Session 1879-80, ...	£2	9	8	*By* Balance in Union Bank, ...	£12 10 6
Dividend on Debenture Stock, Glasgow Corporation Water Works, ...	1	3	8		
Interest on Capital lent to New Buildings Account,	8	16	4		
Bank Interest, ...	0	0	10		
	£12	10	6		£12 10 6

DR. RAILWAY ENGINEERING MEDAL FUND. CR.

To Balance in Union Bank at close of Session 1879-80, ...	£12	9	0	*By* Balance in Union Bank, ...	18 10 9
Dividend on Debenture Stock, Glasgow Corporation Water Works, ...	0	15	7		
Interest on Capital lent to New Buildings Account,	5	2	5		
Bank Interest, ...	0	3	9		
	£18	10	9		£18 10 9

DR. BUILDING FUND. CR.

To Balance in Union Bank at close of Session 1879-80, ...			£112	10	0	*By* Cash to New Buildings Account to meet Interest on Loans, ...	£13 18 9
Six Life Members at £20, ...			120	0	0	Balance in Union Bank, ...	255 3 11
Entry Money, ...			16	10	0		
Dividend on Debenture Stock, Glasgow Corporation Water Works, ...			17	11	7		
Bank Interest, ...			2	11	1		
			£269	2	8		£269 2 8

DR. NEW BUILDINGS ACCOUNT. CR.

To Capital to meet Cost of New Buildings, viz. :—						*By* Paid on New Buildings to date, ...	£1,385 0
From General Fund, ...	£542	15	7			Interest on Loans, viz.:—	
,, Marine Engineering Medal Fund, ...	321	11	2			To Marine Engineering Medal Fund,	£8 16 4
,, Railway Engineering Medal Fund, ...	193	13	3			,, Railway Engineering Medal Fund,	5 2 5
,, Building Fund, ...	327	0	0				£13 18 9
				£1,385	0 0		
Cash received from Building Fund to meet Interest on Loans, ...				13	18 9		
				£1,398	18 9		£1,398 18 9

GLASGOW, *19th April, 1881.*—WE have examined the foregoing Annual Financial Statement of Treasurer, the Accounts of the Marine and Railway Engineering Medal Funds, the Building Fund, and the New Buildings Account, and find the same duly vouched and correct, the Amounts in Bank being as stated.

(Signed) ANDW. MACLEAN, D. KINGHORN, } AUDITORS.

Dr. SUBSCRIPTION ACCOUNT. Cr.

To Subscriptions due as per Roll :—								
Arrears due at close of last Session, ...				£240	10	0		
Deduct since placed on Suspense list and Deceased, ...				73	0	0		
				£167	10	0		
Add elected at Annual Meeting, 1880,				7	0	0		
							174	10	0
Session 1880-81 :—								
331 Members	at	£1	10	0	—	£496	10	0	
12 New Members	,,	2	10	0	—	30	0	0	
10 ,,	,,	2	0	0	—	20	0	0	
8 ,,	,,	1	10	0	—	12	0	0	
32 Associates	,,	1	0	0	—	32	0	0	
2 New Associates		2	0	0	—	4	0	0	
1 ,,	,,	1	10	0	—	1	10	0	
128 Graduates	,,	0	10	0	—	64	0	0	
							660	0	0
							£834	10	0

By Subscriptions received, as per Cash Book :—								
Arrears of Sessions previous to Session 1880-81, ...							£80	10	0
Session 1880-81 :—								
276 Members	at	£1	10	0	—	£414	0	0	
11 New Members	,,	2	10	0	—	27	10	0	
10 ,,	,,	2	0	0	—	20	0	0	
5 ,,	,,	1	10	0	—	7	10	0	
28 Associates	,,	1	0	0	—	28	0	0	
1 New Associate		1	10	0	—	1	10	0	
74 Graduates	,,	0	10	0	—	37	0	0	
							535	10	0
Arrears due for Session 1880-81, ...						£124	10	0	
Arrears due for previous Sessions,						94	0	0	
							218	10	0
							£834	10	0

Dr. BANK ACCOUNT. Cr.

To Balances at close of Session 1879-80 :—			
General Fund, ...	...	£153	17	6
Marine Engineering Medal Fund,	...	2	9	8
Railway Engineering Medal Fund,	...	12	9	0
Building Fund, ...	...	112	10	0
Amounts lodged, Session 1880-81,	...	569	7	5
Interest, Session 1880-81, ...	...	4	7	3
		£855	0	10

By Amounts Drawn, Session 1880-81, ...		£469	18	1
Balance in Union Bank, ...		385	2	9
		£855	0	10

CAPITAL ACCOUNT.

GENERAL FUND.

Loan to New Buildings Account, ...	£542 15 7		
Cash in Union Bank, ...	98 17 7		
		£641	13 2

MARINE ENGINEERING MEDAL FUND.

Loan to New Buildings Account, ...	£321 11 2		
Glasgow Corporation Water Works Debenture Stock, ...	30 0 0		
Cash in Union Bank, ...	12 10 6		
		364	1 8

RAILWAY ENGINEERING MEDAL FUND.

Loan to New Buildings Account, ...	£193 13 3		
Glasgow Corporation Water Works Debenture Stock, ...	20 0 0		
Cash in Union Bank, ...	18 10 9		
		232	4 0

BUILDING FUND.

Glasgow Corporation Water Works Debenture Stock, ...	£450 0 0		
Amount to New Buildings Account, ...	327 0 0		
Cash in Union Bank, ...	255 3 11		
		1032	3 11

ARREARS OF SUBSCRIPTIONS.

Arrears due for Session 1880-81, ...	£124 10 0		
Do. previous Sessions, ...	94 0 0		
		218	10 0
		£2,488	12 9

DONATIONS TO LIBRARY.

"Astronomical Register," and Swan on "Electric Lighting," from Professor C. Piazzi Smyth, F.R.S.

"Resultats obtenus dans l'Emploi des Locomotives Compound sur les Chemins de fer Secondaires," by M. A. Mallet, C.E., Paris; from the Author.

"Recent Methods of Testing Portland Cement," by Mr W. H. Bailey; from the Author.

"Report of the British Association," 1880; from the Association.

"Proceedings of the Engineer Club of Philadelphia," Vol. I., No. 5; from the Society.

"Journal de l'Ecole Polytechnique;" from the Conseil d'Instruction.

"Proceedings Edinburgh and Leith Engineers' Society," Vol. V.; from the Society.

"Contract Journal and Specification Record," London.

"Machinery Market," London.

"Wochenschrift des Osterreichischen Ingenieur und Architekten Vereines," Vienna.

THE INSTITUTION EXCHANGES TRANSACTIONS WITH THE FOLLOWING :—

Institution of Civil Engineers.
Institution of Civil Engineers of Ireland.
Institution of Mechanical Engineers.
Institution of Naval Architects.
Institute of Mining and Mechanical Engineers.
Institute of Mining, Civil, and Mechanical Engineers.
Iron and Steel Institute.
Liverpool Polytechnic Society.
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Patent Office, London.
Philosophical Society of Glasgow.
Royal Scottish Society of Arts.
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South Wales Institute of Engineers.
Society of Engineers.
Society of Arts.
Association of Employers, Foremen, and Draughtsmen, Manchester.
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Royal Society of Tasmania.
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Royal Academy of Sciences, Lisbon.
Société des Ingénieurs Civils de France.
Société Industrielle de Mulhouse.
Société d'Encouragement pour l'Industrie Nationale.
Société des Anciens Elèves des Ecôles Nationales d'Arts et Métiers.
Société des Sciences Physiques et Naturelles de Bordeaux.
Austrian Engineers' and Architects' Society, Vienna.
Engineers and Architects' Society of Naples.

PUBLICATIONS RECEIVED PERIODICALLY IN EXCHANGE FOR INSTITUTION TRANSACTIONS :—

Annales Industrielles.
Annales de la Propriété Industrielle.
Colliery Guardian.
Engineering.
Iron.
Iron and Coal Trades' Review.
Journal de L'Ecole Polytechnic.
Mining Journal.
Nature.
Revue Industrielle.
The Engineer.
The Marine Engineer.

LIST

OF

HONORARY MEMBERS, MEMBERS, ASSOCIATES, AND GRADUATES

OF THE

Institution of Engineers and Shipbuilders in Scotland

(INCORPORATED).

HONORARY MEMBERS.

JAMES PRESCOTT JOULE, LL.D., F.R.S., 12 Wardle Road, Sale, near Manchester.

Professor CHARLES PIAZZI SMYTH, F.R.SS.L. and E., Astronomer-Royal for Scotland, 15 Royal Terrace, Edinburgh.

Professor Sir WILLIAM THOMSON, A.M., LL.D., D.C.L., F.R.SS.L. and E., Professor of Natural Philosophy in the University of Glasgow.

Professor R. CLAUSIUS, the University, Bonn, Prussia.

Sir JOSEPH WHITWORTH, Bart., C.E., LL.D., F.R.S., Manchester.

Professor JOHN TYNDALL, D.C.L., LL.D., F.R.S., &c., Royal Institution, London.

HIS GRACE THE DUKE OF SUTHERLAND, Trentham, Stoke-upon-Trent.

MEMBERS.

DATE OF ELECTION.			
1867, Apr. 24:	Thomas	Adams,	Ant and Bee Works, West Gorton, Manchester.
1859, Jan. 19:	James	*Aitken, jun.,	Shipbuilder, Whiteinch.
1860, Dec 26:	William	Aiton,	Caesygidal, Dyffryn, by Carnarvon, North Wales.
Original:	William	Alexander,	23 India Street, Glasgow.
Original:	Alexander	Allan,	Glen House, The Valley, Scarborough.
1872, Feb. 27:	A. B.	Allan, C.E.,	Burgh Surveyor, Burgh Chambers, Govan.
1869, Jan. 20:	William	Allan,	Sunderland Engine Works, Sunderland.
1864, Dec. 21:	James B.	Alliott,	The Park, Nottingham.
G. 1865, Feb. 15: M. 1877, Dec. 18:	Wm. M.	Alston,	24 Burnbank Gardens, Glasgow.
1880, Apr. 27:	Michael	Altouhoff, C.E.,	26 Fagardney Prospect, St. Petersburg, Russia.
1880, Nov. 23:	Thomas	Anderson,	Government Dockyard, Bombay.
G. 1874, Feb. 24: M. 1880, Nov. 23:	James	Anderson,	100 Clyde St., Glasgow.
1860, Nov. 28:	Robert	Angus,	Lugar Ironworks, Cumnock.
1875, Dec. 21:	Thomas A.	Arroll,	18 Blythswood Square, Glasgow.
Original:	David	Auld,	23 Duncan Street, Calton, Glasgow.
1880, Feb. 24:	William N.	Bain,	East Point, Hong Kong, China.
1873, Apr. 22:	H. W.	Ball,	Cranstonhill Engine Works, Glasgow.

Names marked thus * were Members of Scottish Shipbuilders' Association at Incorporation with Institution, 1865.

Names marked thus † are Life Members.

1858, Dec. 22:	Andrew	Barclay, F.R.A.S.,	Caledonian Foundry, Kilmarnock.
1876, Jan. 25:	James	Barr,	London Road Iron Works, Glasgow.
1868, Apr. 22:	Edward	Barrow,	Directeur du Veritas, 188 Rue Royale, Bruxelles.
1881, Mar. 22:	George H.	Baxter,	Ramage & Ferguson, Leith.
1875, Jan. 26:	Charles	Bell,	4 Clifton Place, Glasgow.
	David	*Bell,	Shipbuilder, Yoker.
1868, Feb. 12:	Edward M.	Bell,	Tinplate Works, Coatbridge.
1880, Mar. 23:	Imrie	Bell, C.E.,	1 Victoria Street, Westminster, London, S.W.
Original:	R. Bruce	Bell, C.E., (*Past President.*)	203 St. Vincent Street, Glasgow.
1880, Nov. 2:	Alfred G.	Berry,	38 Carnarvon St., Glasgow.
	Neil	*Black,	18 Neptune St., Liverpool.
1866, Dec. 26:	Edward	Blackmore,	Eagle Foundry, Greenock.
1864, Oct. 26:	Thomas	Blackwood,	Shipbuilder, Port-Glasgow.
1869, Feb. 17:	Geo. M'L.	Blair,	127 Trongate, Glasgow.
1867, Mar. 27:	James M.	Blair,	2 Cecil Place, Paisley Road, Glasgow.
1874, Jan. 27:	Howard	Bowser,	13 Royal Crescent, W., Glasgow.
1880, Mar. 23:	James	Brand, C.E.,	109 Bath Street, Glasgow.
1865, Apr. 26:	Walter	*Brock,	Engine Works, Dumbarton.
1859, Feb. 16:	Andrew	*Brown,	London Works, Renfrew.
1880, Dec. 21:	William	Brown,	197 Crown Street, Glasgow.
1858, Mar. 17:	James	Brownlee,	23 Burnbank Gardens, Glasgow.
1877, Oct. 30:	Robert	Bruce,	16 St. Enoch Sq., Glasgow.
1860, Dec. 26:	James C.	Bunten,	100 Cheapside St., Glasgow.
1866, Apr. 26:	Amedee	Buquet, C.E.,	13 Boulevard des Batignolles, Paris.
	Andrew	*Burns,	Hilton of Burley, Milnathort.
1880, Dec. 21:	James W.	Burns,	141 Buchanan St., Glasgow.

1881, Mar. 22:	Thomas	Burt,	371 New City Rd., Glasgow.
1878, Oct. 29:	Edward B.	Caird,	8 Scotland St., Glasgow.
1878, Dec. 17:	James	Caldwell,	130 Elliot Street, Glasgow.
1875, Dec. 21:	J. C.	Cameron,	343 Paisley Road, Glasgow.
1880, Dec. 21:	Alexander	Campbell, jun.,	155 North Street, Glasgow.
1870, Nov. 22:	David	Campbell,	151 Eglinton St., Glasgow.
1868, Dec. 23:	David	Carmichael,	Ward Foundry, Dundee.
1859, Nov. 23:	Peter	Carmichael,	Dens Works, Dundee.
1862, Jan. 8:	John	Carrick,	6 Park Quadrant, Glasgow.
1859, Oct. 26:	Robert	Cassels,	168 St. Vincent Street, Glasgow.
1867, Jan. 30:	Albert	Castel,	3 Lombard Court, London, E.C.
1875, Oct. 26:	W. J.	Clark,	Southwick, near Sunderland.
1880, Nov. 2:	James	Clarkson,	Maryhill Engine Works, Maryhill.
1860, Apr. 11:	James	Clinkskill,	1 Holland Place, Glasgow.
1871, Apr. 18:	Jose Maria da	Conceicao,	Rio de Janiero, c/o D. Rowan 231 Elliot St., Glasgow.
	Charles	*Connell,	Whiteinch.
Original:	Robert	Cook,	Woodbine Cottage, Pollokshields.
1864, Feb. 17:	James	Copeland,	16 Pultney St., Glasgow.
1864, Jan. 20:	William R.	Copland, C.E.,	146 W. Regent St., Glasgow.
1868, Mar. 11:	S. G. G. (*Member of Council.*)	Copestake,	Glasgow Locomotive Works, Little Govan, Glasgow.
1866, Nov. 28:	M'Taggart	Cowan, C.E.,	109 Bath Street, Glasgow.
1868, Apr. 22:	David	Cowan, C.E.,	Mt. Gerald House, Falkirk.
1861, Dec. 11:	William	Cowan,	Great North of Scotland Railway, Aberdeen.
1877, Mar. 20:	John	Crawford,	108 Derby Road, Bootle, Liverpool.
1881, Mar. 22:	William	Crockatt,	2 Marjory Place, Pollokshields

1876, Nov. 21: David Croll, 3 Annfield Terrace, W. Partick.
1866, Dec. 26: James L. Cunliff, Inch Works, Port-Glasgow.
1872, Nov. 26: David Cunningham, C.E., Harbour Chambers, Dundee.
1869, Jan. 20: James Currie, 16 Bernard Street, Leith.

1861, Dec. 11: Thomas Davison, 248 Bath Street, Glasgow.
1864, Feb. 17: St. J. V. Day, C.E., 115 St. Vincent St., Glasgow.
1869, Feb. 17: James Deas, C.E., Engineer, Clyde Trust, 16 Robertson St., Glasgow.
1866, Feb. 14: A. C. H. Dekke, Shipb'der, Bergen, Norway.
Peter *Denny, Helenslee, Dumbarton.
1873, Feb. 18: William Denny, Leven Shipy'd, Dumbarton.
1878, Mar. 19: Frank W. Dick, 405 Eglinton St., Glasgow.
G. 1873, Dec. 24: / M. 1878, Jan. 22: James S. Dixon, 19 Elmbank Crescent, Glasgow.
1871, Jan. 17: William Dobson, Shipbuilder, Joy Lodge, Low Walker-on-Tyne.
1864, Jan. 20: James Donald, Abbey Works, Paisley.
1876, Jan. 25: James Donaldson, Fulbar Street, Renfrew.
1863, Nov. 25: Robert Douglas, Dunnikier Foundry, Kirkcaldy.
1864, Oct. 26: Robert *Duncan, Shipbuilder, Port-Glasgow.
(*Past President; Member of Council.*)
1881, Jan. 25: Robert Duncan, Hydepark Street Engine Works, Glasgow.
1873, Apr. 22: Robert Dundas, C.E., 3 Germiston Street, Glasgow.
(*Member of Council.*)
1869, Nov. 23: David Jno. Dunlop, Inch Works, Port-Glasgow.
1877, Jan. 23: John G. Dunlop, 115 King Edward Road, South Hackney, London.
1880, Mar. 23: Hugh S. Dunn, Earlston Villa, Caprington, Kilmarnock.
1879, Dec. 23: Wm. T. Courtier Dutton 30 Gordon St., Glasgow.

1876, Oct. 24: John Marshall Easton, Redholm, Helensburgh.
1865, Oct. 23: Mortimer Evans, C.E., 97 W. Regent St., Glasgow.

1875, Oct. 26: James G. Fairweather, C.E., F.S.A., 12 Buccleuch Pl., George Sq., Edinburgh.
John *Ferguson, Shipbuilder, Whiteinch.
G. 1869, Nov. 23: / M. 1878, Mar. 19: John Ferguson, jun., Shipbuilder, Leith.
1861, Dec. 11: William Ferrie, Monkland Ironworks, Calderbank.
1874, Feb. 24: Immer Fielden, 47 Queen's Square, Belfast.
1880, Jan. 27: Alexander Findlay, c/o James Goodwin & Co., Motherwell.
1876, Oct. 24: Charles Forman, C.E., 160 Hope Street, Glasgow.
Original: William Forrest, 77 Renfield St., Glasgow.
1872, Nov. 26: Thomas Forrest, M.E., Dumfries Ironworks, Dumfries.
1870, Jan. 18: William Foulis, Engineer, Corporation Gas Works, 42 Virginia St., Glasgow.
1880, Nov. 2: Samson Fox, Leeds Forge, Leeds.
1862, Nov. 26: Alexander Fullarton, Vulcan Works, Paisley.
1879, Nov. 25: John Frazer, P. Henderson & Co., 15 St. Vincent Place, Glasgow.

1858, Nov. 24: James M. Gale, C.E., Engineer, Corporation Water Works, 23 Miller Street, Glasgow.
(*Past President; Member of Council and Treasurer.*)
1862, Jan. 8: Andrew Galloway, C.E., St. Enoch Station, Glasgow.
1873, Dec. 23: Bernard Gatow, Veritas Office, 29 Waterloo Street, Glasgow.
1875, Mar. 23: William Gibb, M.E., Palmer & Co., Jarrow-on-Tyne.
1859, Nov. 23: Archibald *Gilchrist, 11 Sandyford Pl., Glasgow.

G. 1866, Dec. 26: M. 1878, Oct. 29:	James	Gilchrist, (*Member of Council.*)	8 Derby Terrace, Glasgow.
1859, Dec. 21:	David C.	Glen,	14 Annfield Place, Glasgow.
1868, Nov. 25:	Thomas	Goldie,	Post Office, Cape Town, Cape of Good Hope.
1864, Feb. 17:	James	Goodwin,	Ironfounder, Ardrossan.
1866, Mar. 28:	Gilbert S.	Goodwin,	Alexandra Buildings, James Street, Liverpool.
1868, Mar. 11:	Joseph	Goodfellow,	83 Taylor Street, Glasgow.
1858, Dec. 22:	Henry	*Gourlay,	Dundee Foundry, Dundee.
	Edwin	*Graham,	Osbourne, Graham, & Co., Hylton, Sunderland.
1858, Mar. 12:	George	Graham, C.E.,	Engineer, Caledonian Railway, Glasgow.
1876, Jan. 25:	Thomas M.	Grant,	Townholm Engine Works, Kilmarnock.
1869, Feb. 17:	Alex. D.	Gray,	Lilybank Boiler Works, Eglinton Street, Glasgow.
1871, Mar. 28:	Thomas	Gray,	Chapel Colliery, Newmains.
1861, Dec. 11:	Archibald	Gray,	Glengarnock Iron Works. Glengarnock.
1862, Jan. 8:	James	Gray,	Pathhead Colliery, Old Cumnock, Ayrshire.
1867, Nov. 27:	James	Grier,	29 Waterloo St., Glasgow.
1870, Feb. 22:	P. B. W.	Gross, M.E.,	4 Albion Place, Cumberland Road, Bristol.
1879, Nov. 25:	Robert	Hadfield,	Hadfield Steel Foundry Co., Attercliffe, Sheffield.
1872, Feb. 27:	A. A.	Haddin, C.E.,	137 W. Regent St., Glasgow.
1881, Jan. 25:	William	Hall, jun.,	Shipbuilder, Aberdeen.
1876, Oct. 24:	David	Halley,	15 Annfield Terrace, Partick, Glasgow.
	James	*Hamilton,	15 Royal Crescent, Glasgow.
G. 1866, Dec. 26: M. 1873, Mar. 18:	James	Hamilton, jn.,	5 Parkgrove Terr., Glasgow.

	John	*Hamilton,	22 Athole Gardens, Gl'gow.
G. 1869, Nov. 23: M. 1875, Feb. 23:	J. B.	Hamond,	The Victoria Engineering Company, Victoria Works, Stockport.
1866, Dec. 26:	James B.	Handyside,	19 Burnbank Gardens, Glasgow.
1876, Feb. 22:	Walter	Hannah,	Board of Trade Surveyor, 7 York Street, Glasgow.
1878, Mar. 19:	Timothy	Harrington,	61 Gracechurch Street, London, E.C.
1875, Jan. 26:	Peter T.	Harris,	19 West St. (S.S.), Glasgow.
G. 1874, Feb. 24: M. 1880, Nov. 23:	C. R.	Harvey, (*Member of Council.*)	166 Renfrew St., Glasgow.
1864, Nov. 23:	John	Hastie,	Kilblain Engine Works, Greenock.
1871, Jan. 17:	William	Hastie,	Kilblain Engine Works, Greenock.
1879, Nov. 25:	A. P.	†Henderson,	30 Lancefield Quay, Glasgow.
1877, Feb. 20:	David	*Henderson,	Meadowside, Partick.
1873, Jan. 21:	John	†Henderson, jun., (*Vice-President.*)	Meadowside, Partick.
1879, Nov. 25:	John L.	†Henderson,	3 Minard Terrace, Partick.
1878, Dec. 17:	William	Henderson,	Meadowside, Partick.
1875, Jan. 26:	William	Henderson,	Bishop Street, Anderston, Glasgow.
1880, Nov. 2:	William	Henderson, C.E.,	1 Catherine St., Dumfries.
1870, May 31:	Richard	Henigan, C.E.,	Alma Terrace, Avenue Road, Southampton.
1877, Feb. 20:	George Laurence	Herriot, *Hill, C.E.,	7 York Street, Glasgow. 59 St. Vincent St., Glasgow.
1880, Nov. 2:	C. P.	Hogg, C.E.,	175 Hope Street, Glasgow.
1880, Mar. 23:	F. G.	Holmes, C.E.,	103 Bath Street, Glasgow.
1874, Mar. 24:	John A.	Hope,	24 Bath Street, Glasgow.
Original:	James	Howden.	8 Scotland Street, Glasgow.
Original:	Edmund	*Hunt,	87 St. Vincent St., Glasgow.

1860, Nov. 28:	James	Hunter,	Coltness Iron Works, by Newmains.
1881, Jan. 25:	James	Hunter,	Aberdeen Iron Works, Aberdeen.
1857, Dec. 23:	John	Hunter,	Dalmellington Iron Works, near Ayr.
G. 1873, Dec. 23: / M. 1877, Feb. 20:	P. S.	Hyslop,	Public Works Department, Cape Town, S'th Africa.
	Anthony	*Inglis,	64 Warroch Street, Glasgow.
Original:	John	*Inglis,	64 Warroch Street, Glasgow.
1861, May 1:	John	Inglis, junr.,	Point House Shipyard, Glasgow.
1872, Nov. 26:	Josh. Hyde	Irwin, M.E.,	11 Aubery Ter., Sunderland.
1879, Jan. 21:	Thos. F.	Irwin,	Inman Steamship Coy., Liverpool.
1880, Nov. 2:	Lawrence N.	Jackson,	Engineer, Railway Works, Colombo, Ceylon.
1875, Dec. 21:	William	Jackson,	Govan Engine Works, Govan.
	Geo. W.	*Jaffrey,	17 Robertson St., Greenock.
1867, Dec. 26:	John L. K.	Jamieson, (*President.*)	9 Crown Terr., Dowanhill, Glasgow.
1879, Feb. 25:	David	Johnstone,	7 Carmichael St., Govan.
1870, Dec. 20:	David	Jones,	Highland Rlwy., Inverness.
1872, Mar. 26:	Ebenezer	Kemp,	Linthouse Engine Works, Govan.
1875, Nov. 23:	William	Kemp,	Ellen St. Engineering Works, Govan.
1878, Mar. 19:	Hugh	Kennedy,	Redclyffe, Partickhill.
1877, Jan. 23:	John	Kennedy,	Bond Court Chambers, Walbrook, London, E.C.
1876, Feb. 22:	Thomas	Kennedy,	Water Meter Works, Kilmarnock.

1876, Oct. 24:	Andrew	Kerr, C.E.,	Warrnambool, Victoria, Australia.
1876, Mar. 21:	John G.	Kincaid,	Clyde Foundry, Greenock.
	David	Kinghorn,	172 Lancefield St., Glasgow.
1879, Dec. 23:	John G.	Kinghorn,	2 Alexandra Terrace, Rock Ferry, Cheshire.
1864, Oct. 26:	Alex. C.	Kirk, (*Member of Council.*)	17 Hillsborough Square, Hillhead.
Original:	David	*Kirkaldy,	Testing and Experimenting Works, Southwark St., London, S.E.
1880, Mar. 23:	Frederick	Krebs,	M.B.M.S.S. Co., Tokio, Japan.
1875 Oct. 26:	William	Laing,	72 Gt. Clyde St., Glasgow.
1858, Apr. 14:	David	Laidlaw,	147 E. Milton St., Glasgow.
1862, Nov. 26:	Robert	Laidlaw,	147 E. Milton St., Glasgow.
1880, Feb. 24:	James	Lang,	Superintendent Engineer, Kobe, Japan.
1864, Oct. 26:	George	Lauder, C.E.,	c/o Carnegie & Co., Coke Works, near Larimer Station, Pa., United States of America.
Original:	James G.	*Lawrie, (*Past President.*)	2 Westbourne Terrace, Glasgow.
	Andrew	*Leckie, Surveyor,	Commercial Buildings, West Hartlepool.
1880, Mar. 23:	Allison	Lennox,	131 W. Regent St., Glasgow.
1878, Mar. 19:	John	Lennox,	131 W. Regent St., Glasgow.
1875, Feb. 23:	Robert	Liddell,	1 Stanley Pl., Uddingston.
G. 1873, Dec. 23: / M. 1876, Oct. 24:	Charles C.	Lindsay, C.E., (*Member of Council.*)	203 St. Vincent St., Glasgow.
1862, Apr. 2:	H. C.	Lobnitz,	Renfrew.
1865, Dec. 20:	John L.	Lumsden,	Fairfield Shipyard, Govan.
	James	*Lyall,	13A Exchange Buildings, Liverpool.

1873, Jan. 21:	James M.	Lyon, M.E.,	Singapore
1862, Oct. 29:	John	M'Andrew,	17 Park St. East, Glasgow.
1858, Feb. 17:	David	M'Call, C.E.,	160 Hope Street, Glasgow.
1874, Mar. 24:	Hector	MacColl,	Jas. Jack & Co., Engineers, Liverpool.
	Hugh	*MacColl,	Manager, Wear Dock Yard, Sunderland.
1878, Oct. 29:	James G.	M'Culloch,	Marine Board Dept., Adelaide, Australia.
1871, Jan. 17:	David	M'Culloch,	Vulcan Works, Kilmarnock.
1857, Dec. 23:	J. I.	M'Derment,	39 Sandgate Street, Ayr.
1880, Nov. 2:	James W.	Macfarlane,	Lochburn Iron Works, Maryhill.
Original:	Walter	MacFarlane,	Possil Park, Glasgow.
	Andrew	*M'Geachan,	Newark Shipbuilding Yard, Port-Glasgow.
1879, Mar. 25:	Josiah	M'Gregor, C.E.,	4 Cavendish Park, Barrow-in-Furness.
Original:	James	M'Ilwham,	100 Cheapside Street, Glasgow.
1880, Apr. 27:	Wm. Rae	M'Kaig,	17 Water St., Liverpool.
1858, Apr. 14:	John	Mackenzie, M.E.,	Ashgrove Villa, Ibroxholm.
1881, Mar. 22:	William A.	Mackie,	26 S. Portland St., Glasgow.
1873, Jan. 21:	J.B. Affleck	M'Kinnel,	Dumfries Iron Works, Dumfries.
1876, Dec. 19:	R. B.	MacKinnon,	R. Laidlaw & Sons, Liverpool.
1859, Dec 21:	Robert	M'Laren,	22 Canal St., S.S., Glasgow.
	Andrew	*Maclean,	Viewfield House, Partick.
1858, Nov. 24:	Walter	M'Lellan,	127 Trongate, Glasgow.
	John	*M'Millan,	Shipbuilder, Dumbarton.
	William	*MacMillan,	19 Elgin Terrace, Partick.
Original:	William	M'Nab,	3 Eastfield Ter., Rutherglen.

Original:	Andrew	M'Onie,	1 Scotland Street, Glasgow.
1864, Oct. 26:	Robert	*Mansel,	Shipbuilder, Whiteinch.
	(*Past President; Member of Council.*)		
1867, Oct. 30:	John	Mather,	London and South-Western Rlwy., Nine Elms Works, London, S.W.
1875, Dec. 21:	George	Mathewson,	Bothwell Works, Dunfermline.
1876, Jan. 25:	William W.	May.	276 Fountains Road, Walton, Liverpool.
1881, Mar. 22:	William	Menzies,	9 Dean Street, Newcastle-on-Tyne.
1861, Dec. 11:	Daniel	Miller, C.E.,	203 St. Vincent Street, Glasgow.
	James	*Miller,	Kelvin Forge, Partick.
1875, Oct. 26:	Leighton	Mills,	Principal Board of Trade Officer, N. E. District, Tynemouth.
Original:	James B.	Mirrlees,	45 Scotland St., Glasgow.
1857, Dec. 23:	John	Moffat, C.E.,	Ardrossan.
1876, Mar. 21:	James	Mollison,	Lloyd's Register, 36 Oswald Street, Glasgow.
1869, Dec. 21:	John	Montgomerie,	Caledonian Railway Works, Perth.
1864, Jan. 21:	William	Moore, C.E.,	49 W. George St., Glasgow.
1862, Nov. 26:	Ralph	Moore, C.E.,	Croft Villa, Rutherglen.
	(*Vice-President.*)		
1878, Apr. 23:	Robert H.	Moore,	Parkhead Forge, Glasgow.
1868, Feb. 12:	Alexander	Morton,	32 Windsor Ter., Glasgow.
1864, Feb. 17:	Hugh	Muir,	345 Bath Crescent, Glasgow.
1870, Mar. 22:	Wm. T.	Mumford,	36 Oswald Street, Glasgow.
Original:	James	Murdoch,	Shipbuilder, Port-Glasgow.
1880, Jan. 27:	William	Murdoch,	77 S. Portland St., Glasgow.
1874, Mar. 24:	Richard	Murray,	160 Hope Street, Glasgow.
1877, Jun. 23:	Robert	Murray,	25A Coltman Street, Hull.

1881, Jan. 25: Henry M. Napier, Shipbuilder, Yoker.
1857, Dec. 23: John †*Napier. 23 Portman Sq., London.
Original: Walter Neilson, 172 West George Street, Glasgow.
Original: Walter M. Neilson, (*Past President.*) Queen's Hill Kirkcudbrightshire.
1858, Jan. 20: William Neilson, 92 W. Regent St., Glasgow.
1869, Nov. 23: Theod. L. Neish, Broughty Ferry, by Dundee.
A 1865, Apr. 26:* } R. S. Newall, F.R.S., F.R.A.S., &c.,
M. 1879, Oct. 28: } Ferndene, Gateshead on-Tyne.
Benjamin *Nicholson, Annan.
1876, Dec. 19: Richard Niven, C.E., Dalnottar House, Old Kilpatrick.
1876, Jan. 25: Thomas Ogilvie Niven, C.E., 115 Wellington Street, Glasgow.
1861, Dec. 11: John Norman, 16 Pulteney St., Glasgow.
1860, Nov. 28: John W. Ormiston, Shotts Iron Works, by Wishaw.
1880, Nov. 2. Thomas †Ormiston, C.I E., Ormidale Thurlowpark Road, N. Dulwich, London, E.C.
1867, Apr. 24: T. R. Oswald, The Southampton Shipbuilding & Engineering Works, Southampton.
1864, Oct. 26: John Page, C.E., 39 Arlington Street, Glasgow.
1876, Apr. 25: William Parker, 2 White Lion Court, Cornhill, London.
1877, Apr. 24: Andrew Paul, Levenford Works, Dumbarton.
1880, Nov. 2: James M. Pearson, C.E., 8 Duke St., Kilmarnock.
1866, Dec. 26: William Pearce, Fairfield Shipyard, Govan.
1868, Dec. 23: Eugène Perignon, C.E., 105 Rue Faubourg, St. Honoré, Paris.

	John	*Price,	Rose Villa, Gateshead Road, Jarrow-on-Tyne.
1875, Dec. 21:	Matthew	Prior,	56 Ellesmere Rd., Sheffield.
1877, Nov. 20:	F. P.	Purvis,	14 Strathleven Place, Dumbarton.
1868, Dec. 23:	Henry M.	Rait,	155 Fenchurch St., London.
1873, Apr. 22:	Richard	Ramage,	Shipbuilder, Leith.
1866, Dec. 26:	Daniel	Rankin,	Eagle Foundry, Greenock.
1872, Oct. 22:	David	Rankine,	75 West Nile Street, Glasgow.
1876, Dec. 19:	Robert	Rankin,	35 Paisley Road, Glasgow.
1876, Oct. 24:	Thomas E.	Rawlinson, C.E.,	Britannia Lodge, 2 Lyon's Road, Southport.
1881, Jan. 25:	Charles	Reid,	Lobymount, Kilmarnock.
1868, Mar. 11:	James	Reid, *(Vice-President.)*	Locomotive Works, Springburn.
1869, Mar. 17:	James	Reid,	Shipbuilder, Port Glasgow.
	John	*Reid,	Shipbuilder, Port-Glasgow.
1880, Apr. 27:	John	Rennie,	Kiangnan Arsenal, Shanghai, China.
1876, Oct. 24:	Duncan	Robertson,	30 Gordon Street, Glasgow.
Original:	James	Robertson,	Stanley St., Kinning Park, Glasgow.
1873, Jan. 21:	John	Robertson,	Grange Knowe, Pollokshields.
1873, Apr. 22:	M. W.	Robertson,	Avon Steel Works, Duke Street, Glasgow.
1863, Nov. 25:	William	Robertson,	C.E., 123 St. Vincent Street, Glasgow.
Original:	Hazltn. R.	*Robson, *(Past President; Member of Council.)*	14 Royal Cresct., Glasgow.
1877, Feb. 20:	Jno. Macdonald	Ross,	11 Queen's Cres., Glasgow.
1861, Dec. 11:	Richard G.	Ross,	21 Greenhead St., Glasgow.
G. 1864, Nov. 23: M. 1870, Jan. 18:	Alex.	Ross, C.E.,	Alva.

Original: David *Rowan, 231 Elliot Street, Glasgow.
(*Past President; Member of Council.*)

1876, Oct. 24: Alfred Rumball, C.E., 23 Parliamentary Street, Westminster, S.W.

G. 1858, Dec. 22:
M. 1863, Mar. 4: George Russell, Engineer, Motherwell.

1877, Oct. 30: Alexander Russell, 100 Cheapside St., Glasgow.

1859, Dec. 21: Thomas *Russell, Albyn Lodge, Bridge of Allan.

1881, Feb. 22: Joseph Russell, Shipbuilder, Port-Glasgow.

1876, Oct. 24: Peter Samson, Board of Trade Offices, Downing Street, London, S.W.

1872, Jan. 30: James E. Scott, Shipbuilder, Eldon Street, Greenock.

1860, Nov. 28: Thos. B. *Seath, 42 Broomielaw, Glasgow.

1881, Jan. 25: John Scott, Aberdeen Iron Works, Aberdeen.

1875, Jan. 26: Alexander Shanks, Belgrade, Ayton Road, Pollokshields.

1858, Nov. 24: William Simons, Renfrew.

1862, Jan. 22: Alexander Simpson, C.E., 175 Hope Street, Glasgow.

1871, Mar. 28: Hugh Smellie, Belmont Grange Terrace, Kilmarnock.

Original: Alexander Smith, 57 Cook Street, Glasgow.

1880, Nov. 2: Alexander Smith, 9 Stanley Pl., Paisley Road

1869, Mar. 17: David S. Smith, Hellenic Steam Navigation Co., Syra, Greece.

1859, Jan. 19: George Smith, Kennedy Street, Parliamentary Road, Glasgow.

1861, Dec. 11: Hugh Smith, Possil Engine Works, Killearn Street.

G. 1868, Dec. 23:
M. 1874, Oct. 27: Hugh Smith, Partick Engine Works, Partick.

1878, May 14:	James	Smith,	40 Margaret St., Greenock.
1870, Feb. 22:	Edward	Snowball,	Engineer, Hyde Park Locomotive Works, Springburn.
Original:	Robert	*Steele,	Shipbuilder, Greenock.
	William	*Steele,	Shipbuilder, Greenock.
	John	*Stephen,	Linthouse, Govan.
1859, Jan. 19:	David Y.	Stewart,	3 Provan Place, Glasgow.
1867, Jan. 30:	Duncan	Stewart,	47 Summer Street, Glasgow.
1874, Oct. 27:	Peter	Stewart,	53 Renfield Street, Glasgow.
1866, Nov. 28:	James	Stirling,	Loco. Engineer, S. Eastern Ry., Ashford, Kent.
Original:	Patrick	Stirling,	The Great Northern Railway, Doncaster.
1881, Jan. 25:	Walter	Stoddart,	Caledonian Railway, Carstairs.
1864, Nov. 23:	Edward	Strong,	°/₀ Kent Cottage, Queen's Cres., Southsea, Hants.
1877, Jan. 23:	James	Syme,	358 Paisley Road (West), Govan.
1879, Oct. 28:	James	Tait, C.E.,	Wishaw.
1879, Mar. 25:	Stavely	Taylor,	38 Gordon Street, Glasgow.
1873, Dec. 23:	E. L.	Tessier,	Veritas Office, 29 Waterloo Street, Glasgow.
1874, Nov. 24:	Prof. James	Thomson,	F.R.S.S.L. & E., LL.D., C.E., Oakfield House, University Avenue, Glasgow.
1868, Feb. 12:	James M.	Thomson,	36 Finnieston St., Glasgow.
1868, May 20:	John	Thomson,	36 Finnieston St., Glasgow.
1876, Feb. 22:	John	Thomson,	147 E. Milton St., Glasgow.
1875, Jan. 26:	Robert S.	Thomson,	19 Windsor St., Glasgow.
1864, Feb. 17:	W. R. M.	Thomson,	96 Buchanan St., Glasgow.
1878, May 14:	W. B.	Thompson,	Tay View, Broughty Ferry.
G. 1862, Dec. 24: / M. 1878, Oct. 29:	Cornelius	Thompson,	17 Albyn Place, Aberdeen.

Original:	Thomas C.	Thorburn,	35 Hamilton Square, Birkenhead.
1874, Oct. 27	Prof. R. H.	Thurston, M.E., C.E.,	Steven's Institute of Technology, Hoboken, N. Jersey, U.S.A.
1875, Nov. 23:	John	Turnbull, jun.,	Consulting Engineer, 184 Buchanan St., Glasgow.
1876, Nov. 21:	Alexander	Turnbull,	5 Gartocher Ter., Shettleston.
1876, Jan. 25:	Henry	Turner,	Managing Engineer, Canada Works, Birkenhead.
1880, Apr. 27:	John	Tweedy,	Neptune Works, Newcastle-on Tyne.
1880, Nov. 2:	Ralph H.	Tweddell,	14 Delahay Street, Westminster.
1865, Apr. 26:	W. W.	Urquhart,	Blackness Foundry, Dundee.
1872, Mar. 26:	Henry Hay	Wake,	Engineer, River Wear Commission, Sunderland.
1872, Nov. 26:	Nicholas	Watts, C.E.,	34 Porchester Square, London, W.
1875, Mar. 23:	G. L.	Watson,	108 W. Regent St., Glasgow.
1864, Mar. 16:	W. R. (*Member of Council.*)	Watson,	16 Woodlands Ter., Glasgow.
1865, Apr. 26:	William	Weems,	Engineer, Johnstone.
	John	*Weild,	Underwriter, Exchange, Glasgow.
1874, Dec. 22:	George	Weir, M.E.,	18 Millbrae Cres., Langside.
1874, Dec. 22:	James	Weir, M.E.,	Silver Bank, Cambuslang.
1869, Feb. 17:	Thomas M.	Welsh,	63 St. Vincent Cres., Glasgow.
1868, Dec. 23:	Henry H.	West,	13A Exchange Buildings, Liverpool.
1876, Oct. 24:	Francis W.	Willcox,	64 Fawcett St., Sunderland.
1875, Dec. 21:	John	Williams,	Marine Engineer, °/o Messrs M'Kinnon, M'Kenzie, & Co., Calcutta.

1878, Oct. 29:	Thomas	Williamson,	1 Alexandra Parade, Glasgow.
Original:	John	Wilkie,	33 Renfield St., Glasgow.
1874, Feb. 24:	Alexander	Wilson,	Engineer Surv., Harbour Office, Melbourne.
	Alex. H.	*Wilson,	Aberdeen Iron Works, Aberdeen.
1868, Dec. 23:	James	Wilson, C.E.,	Water Works, Greenock.
1863, Mar. 18:	James E.	Wilson,	1 Ranfurly Place, Paisley Road, Glasgow.
1876, Oct. 24:	Jno. Paul	Wilson,	Tweed Shipbuilding Yard, Berwick-on-Tweed.
1870, Feb. 22:	John	Wilson,	Florence Bank, Hillside Terrace, Springburn.
1858, Jan. 20:	Thomas	†*Wingate,	Viewfield, Partick.
1880, Nov. 2:	Alexander	Wood,	29 Ashton Ter., Glasgow.
1879, Oct. 28:	John	Young,	Phœnix Iron Works, Glasgow.
1867, Nov. 27:	John	Young,	Galbraith Street, Stobcross, Glasgow.
1870 Nov. 22:	William	Young,	Vulcan Foundry, Ayr.

ASSOCIATES.

	Thomas	*Aitken,	8 Dock Place, Leith.
	Andrew	*Armour,	68 Anderston Quay, Glasgow.
	T. S.	*Begbie,	36 Walbrook, London, E.C.
	Capt. Alex.	*Blackwood,	Leith.
1876, Jan. 25:	John	Brown,	11 Somerset Place, Glasgow.
1877, Nov. 20:	Capt. Wm.	Brown,	15 St. Vincent Pl., Glasgow.
1865, Jan. 18:	John	Bryce,	82 Oswald Street, Glasgow.

Names marked thus * were Associates of Scottish Shipbuilders' Association at Incorporation with Institution, 1865.

1880, Dec. 21: John Cassells, 56 Cook Street, Glasgow.
1875, Feb. 23: Daniel Cocking, 202 Hope Street, Glasgow.
1870, Dec. 20: Joseph J. Coleman, F.C.S., 45 W. Nile St., Glasgow.

1859, Nov. 23: Arch. Orr Ewing, M.P., 2 W. Regent St., Glasgow.

1863, Mar. 18: Robert Gardner, 52 North Frederick Street, Glasgow.

1865, Dec. 20: James Haddow, 43 Oswald Street, Glasgow.
1860, Jan. 18: George T. Hendry, 79 Gt. Clyde St., Glasgow.

1864, Dec. 21: Anderson Kirkwood, LL.D., 7 Melville Ter., Stirling.

1878, Oct. 29: John Langlands, 88 Gt. Clyde St., Glasgow.
1865, Dec. 20: John Jex Long, 12 Whitevale, Glasgow.

1880, Nov. 2: George M'Callum, 322 Castle Street, Glasgow.
1874, Mar. 24: Peter Marshall, 6 Park Grove Ter., Glasgow.
1873, Feb. 18: John Mayer, F.C.S. 2 Clarinda Terrace, Pollokshields.
1874, Mar. 24: James B. Mercer, Broughton Copper Works, Manchester.
George *Miller, 1 Wellesley Place, Glasgow.
1865, Dec. 20: John Morgan, Springfield House, Bishopbriggs.
James S. *Napier, 33 Oswald Street, Glasgow.
John Phillips, 17 Anderston Quay, Glasgow.

1869, Nov. 23: Capt. John Rankine, 31 Airlie Terrace, Pollokshields.
1867, Dec. 11: William H. Richardson, 19 Kyle Street, Glasgow.

1876, Jan. 25: George Smith, 101 St. Vincent St., Glasgow.

	John	*Smith,	Aberdeen Steam Navigation Co., Aberdeen.
1880, Nov. 2:	John	Stedman,	103 Cathcart Street.
	Malcolm M'N.	*Walker,	45 Clyde Place, Glasgow.
	H. J.	*Watson,	62 Jamaica Street, Glasgow.
	T.	*Westhorp,	West India Road, London.
1860, Nov. 28:	James	Young,	Kelly, Wemyss Bay.
	William	*Young,	Galbraith Street, Stobcross, Glasgow.

GRADUATES.

1880, Nov. 2:	James	Aitken,	15 Dixon Avenue, Crosshill.
1880, Feb. 24:	George	Almond,	Belmont, Bolton-le-Moors, Lancashire.
1870, Apr. 19:	John	Anderson,	c/o J. H. W. Shaw, 115 Buchanan St., Glasgow.
1876, Dec. 19:	Robert	Anderson,	175 Hope Street, Glasgow.
1875, Dec. 21:	George	Arnison, jun.,	81 Berry Street, Bootle, Liverpool.
1877, Nov. 20:	James T.	Baxter,	146 W. Regent St., Glasgow.
1871, Feb. 21:	W. S.	Beck,	26 Granville St., Glasgow.
1880, Mar. 23:	Alexander	Bowie,	5 India Street, Glasgow.
1873, Dec. 23:	Wm. G.	Bowser,	Great Wellington St., Paisley Road, Glasgow.
1878, Dec. 17:	Rowland	Brittain,	18 Petershill Rd., Glasgow.
1873, Dec. 23:	James	Broadfoot, jun.,	4 La Belle Place, Glasgow.
1876, Jan. 25:	A. M'N.	Brown,	Castlehill House, Renfrew.
1874, Jan. 27:	William	Brown,	Castlehill House, Renfrew.
1879, Feb. 25:	Alex. T.	Brown,	116 South Portland Street, Glasgow.
1881, Jan. 25:	Matthew T.	Brown, B.Sc.,	13 Berlin Ter., Glasgow

1872, Oct. 22: Hartvig	Burmeister,	c/o Rahr & Raundrap, 14 Brown St., Manchester.
1876, Dec. 19: Lindsay	Burnet,	49 Albany Street, Leith.
1873, Dec. 23: David	Campbell,	Milton Iron & Steel Works, Motherwell.
1873, Dec. 23: Walter M.	Chambers,	Laird Brothers, Engineers and Shipbuilders, Birkenhead.
1876, Dec. 19: Charles	Connell, jr.,	Rozelle, Partick.
1877, Dec. 18: James	Conner,	9 Scott Street, Glasgow.
1876, Jan. 25: William M.	Cooke,	Dundee Foundry, Dundee.
1874, Feb. 24: Andrew	Corbett,	Kelvinhaugh Street Engine Works, Glasgow.
1880, Dec. 21: Sinclair	Couper,	Coatswood House, Coatbridge.
1880, Nov. 23: James M.	Croom,	84 Buccleuch Street, Glasgow.
1874, Feb. 24: James	Davie,	352 St. Vincent St., Glasgow.
1881, Mar. 22: D.	Davidson,	15 Beaufort Ter., Glasgow.
1879, Oct. 28: Jonathan L.	Dean,	4 Harlington Road, Middlesbro'.
1873, Dec. 23: Peter	Dewar,	25 North Street, Glasgow.
1879, Nov. 25: Alex. B.	Dobbie,	292 St. Vincent St., Glasgow.
1880, Nov. 2: Geo. C.	Douglas,	108 N. Hanover Street, Glasgow.
1878, Jan. 22: James R.	Faill,	Craig-en-Callie, Ayr.
1880, Dec. 21: Henry M.	Fellows,	109 North St., Glasgow.
1875, Apr. 27: Charles	Fergus,	Bishop Street, Glasgow.
1881, Feb. 22: William	Ferguson,	Larkfield, Partick.
1873, Dec. 23: E. Walton	Findlay,	Ardeer, Stevenston.
1874, Feb. 24: John	Fleming,	52 Dumbarton Rd., Glasgow.
1869, Oct. 26: F. P.	Fletcher,	Engineer Office, Mid. Railway, Derby.
1880, Dec. 21: Robert	Fulton,	8 Margaret Street, Glasgow.

1873, Dec. 23: Andrew	Gibb,	°/o Milwall Dock Engineering Works, Milwall Docks, London.
1874, Feb. 24: James	Gillespie,	21 Cleveland St., Glasgow.
1874, Feb. 24: James	Grier, jun.,	29 Waterloo St., Glasgow.
1874, Feb. 24: Archibald	Hamilton,	16 Robertson St., Glasgow.
1873, Dec. 23: David C.	Hamilton,	Clyde Shipping Co., 2 Oswald Street, Glasgow.
1881, Jan. 25: Stephen	Hands,	9 Minerva Street.
1880, Nov. 2: Bruce	Harman,	Lancefield Street, Glasgow.
1881, Feb. 22: James	Harvey,	Whithorn Villa, Pollokshields.
1881, Jan. 25: A. C.	Holms,	Hope Park, Partick.
1880, Dec. 21: Duncan	Houston,	21 Alexander St., Glasgow.
1873, Dec. 23: Guybon	Hutson,	Kelvinhaugh Engine Works, Glasgow.
1877, Mar. 20: Alex. C.	Jameson,	Edinburgh University.
1873, Dec. 23: David	Johnston,	12 York Street, Glasgow.
1880, Nov. 2: L. P.	Johnson,	10 Spiers Place, Queen Mary's Avenue, Crosshill.
1880, Jan. 27: Robert	Kerr,	109 Bath Street, Glasgow.
1878, Jan. 22: Easton	Knox,	47 Crownpoint Road, Mile End, Glasgow.
1880, Nov. 2: John	Kyle,	203 St. Vincent Street, Glasgow.
1880, Nov. 2: Patrick F.	M'Callum,	Dalzell Steel Works, Motherwell.
1876, Oct. 24: Jno. M.	M'Currich,	M.A., 203 St. Vincent Street, Glasgow.
1879, Jan. 21: James	M'Farlane,	40 Claremont St., Glasgow.
1874, Feb. 24: George	M'Farlane,	65 Gt. Clyde St., Glasgow.

1880, Feb. 24: Neil	M'Kechnie,	31 Bank Street, Hillhead.
1876, Dec. 19: John	M'Kirdy,	Bridge Works, Motherwell.
1880, Nov. 2: Robert	M'Laren, jr.,	Eglinton Foundry, Glasgow.
1875, Dec. 21: Hugh	M'Lachlan,	5 Dowanhill Pl., Partick.
1881, Apr. 26: Hugh	M'Millan,	Blochairn Steel Works, Glasgow.
1875, Dec. 21: Allister	M'Niven,	Clutha Iron Works, Vermont Street, Glasgow.
1880, Jan. 27: G. Scott	M'Ritchie,	Jack & Co., Sandon Dock, Liverpool.
1879, Oct. 28: Donald	M'Taggart,	38 Dover Street, Glasgow.
1874, Feb. 24: Andrew	Maclean, jun.,	Viewfield House, Partick.
1874, Feb. 24: William	Maclean,	Viewfield House, Partick.
1874, Feb. 24: Alexander	Malloch,	Linwood, Renfrewshire.
1878, Jan. 21: Robert	Marshall,	17 Minerva St., Glasgow.
1880, Nov. 2: Ivan	Mavor,	Devon Bank, Pollokshields.
1876, Oct. 24: James	Meldrum,	R. Ward & Co., 139 St. Vincent St., Glasgow.
1880, Feb. 24: Robert	Miller,	1 Wellesley Place, Sandyford, Glasgow.
1873, Dec. 23: George	Miller, jun.,	268 Bath Cres., Glasgow.
1873, Dec. 23: John F.	Miller,	13 Park Grove Terrace, Glasgow.
1879, Jan. 21: Alexander	Mitchell,	55 Kelvinhaugh St., Glasgow.
1880, Feb. 24: James F.	Mitchell,	23 St. Vincent Crescent, Glasgow.
1881, Jan. 25: Ernest W.	Moir.	91 Kent Road, Glasgow.
1877, Dec. 18: John	Moore,	26 Raglan St., Glasgow.
1880, Jan. 27: James	Morton,	128 Byars Road, Glasgow.
1878, Dec. 17: Robert	Morton,	164½ Buchanan Street, Glasgow.
1878, May 14: Angus	Murray,	47 Kelvinhaugh St., Glasgow.
1875, Dec. 21: James S.	Murray,	3 Callander Place, Cathcart Road, Glasgow.

1873, Dec. 23: George A.	Newall,	St. Philip Iron Works, Bristol.
1881, Feb. 21: Samuel B.	Newton,	3 Westmoreland St., Gl'gow.
1876, Jan. 25: Thos. G. F.	Palmer	Clutha Iron Works, Vermont Street, Glasgow.
1880, Mar. 23: J.	Patterson, jn.,	1 Alberta Terrace, Byars Road, Glasgow.
1879, Nov. 25: Alex. R.	Paton,	Redthorn, Partick.
1873, Dec. 23: Edward C.	Peck,	Yarrow & Co., Poplar, London, E.
1880, Jan. 27: James S.	Porter,	410 St. Vincent St., Glasgow.
1880, Nov. 2: Matthew	Rankine,	3 Wilton Cres., Glasgow.
1875, Apr. 27: Robert	Rankine,	51 Gardner Street, Glasgow.
1873, Dec. 23: Charles H.	Reynolds,	9 Broomhill Terrace, (West), Partick.
1878, Dec. 17: James R.	Ross,	c/o Mirrlees, Tait, & Watson, Scotland Street, Glasgow.
1875, Dec. 21: James	Rowan,	22 Woodside Pl., Glasgow.
1879, Nov. 25: Charles G.	Russell,	Walkenshaw Foundry, Johnstone.
1879, Nov. 25: Robert	Russell,	Craigie Bank, Crosshill.
1875, Oct. 26: Magnus	Sandison,	455 Paisley Road, Glasgow.
1879, Mar. 25: John	Scobie,	Culdees Minard Rd., Partickhill.
1880, Apr. 27: Archibald	Sharp,	31 Morrison St., Glasgow.
1880, Jan. 27: H.	Sherlock,	9 Deans Yard, Westminster, S.W.
1880, Mar. 23: Robert M.	Short,	5 Maxwell Street, Partick.
1877, Mar. 20: Nisbet	Sinclair, jun.,	2 Clelland Place, Paisley Road, Glasgow.
1877, Nov. 20: Robert	Smith,	Parkgrove Iron Works, Kinning Park, Glasgow.
1881, Jan. 25: William	Stevenson,	220 Berkeley St., Glasgow.

1873, Dec. 23: John	Stewart,	270 New City Rd., Glasgow.
1879, Feb. 25: James	Stewart,	Coatswood House, Coatbridge.
1877, Oct. 30: Thomas	Stewart,	23 Miller Street, Glasgow.
1873, Dec. 23: W. B.	Stewart,	2 Provan Place, Glasgow.
1875, Dec. 21: Andrew	Stirling,	98 Dumbarton Road, Glasgow.
1877, Jan. 23: George	Stirratt,	26 Lynedoch St., Glasgow.
1878, Jan. 22: Benj. B.	Sykes,	Caledonian Railway Works, Polmadie Road.
1880, Dec. 21: Stanley	Tatham,	7 Radnor Terrace, Dumbarton Road.
1880, Nov. 23: George	Thomson,	Alpha Works, Motherwell.
1874, Feb. 24: George C.	Thomson,	77 Hill Street, Garnethill, Glasgow.
1878, Dec. 17: James	Watson,	138 W. Regent St., Glasgow.
1881, Mar. 22: Robert	Watson,	318 St. Vincent St., Glasgow.
1880, Apr. 27: Robert D.	Watt,	9 Osborne Terrace, Govan.
1875, Dec. 21: Richard G.	Webb,	Clutha Iron Works, Gl'gow.
1878, Dec. 17: Robert L.	Weighton,	123 Dumbarton Rd., Gl'gow.
1876, Dec. 19: Thomas D.	Weir,	Downham Market, Norfolkshire.
1874, Feb. 24: William	Whyte,	37 Dorset Street, Glasgow.
1877, Jan. 23: Robt. John	Wight,	7 Berlin Place, Pollokshields.
1879, Oct. 28: William	Willox, M.A.,	203 St. Vincent St., Glasgow.
1873, Dec. 23: Robert	Wyllie,	7 Ibrox Place, Govan.
1873, Dec. 23: Robert	Young,	188 Buchanan St., Glasgow.

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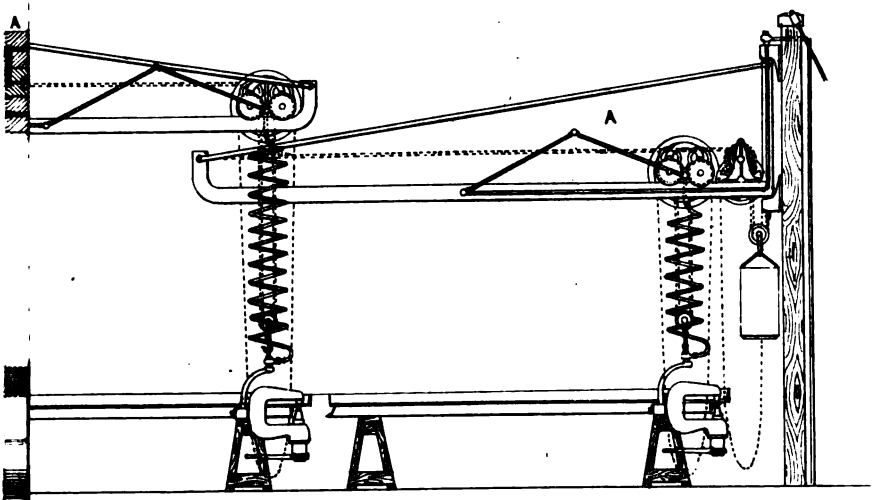

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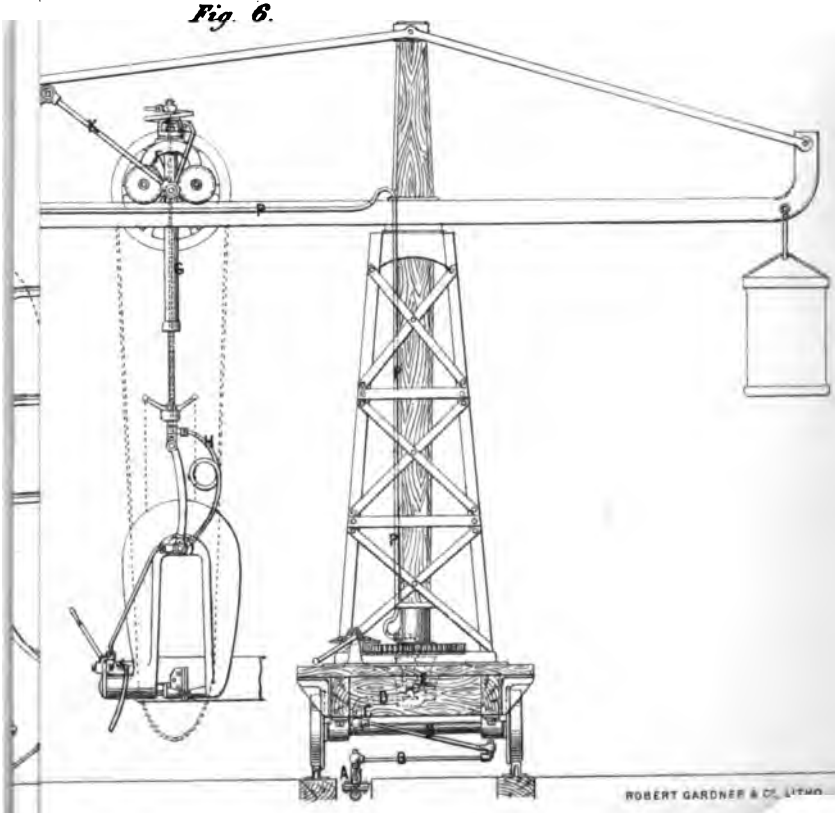

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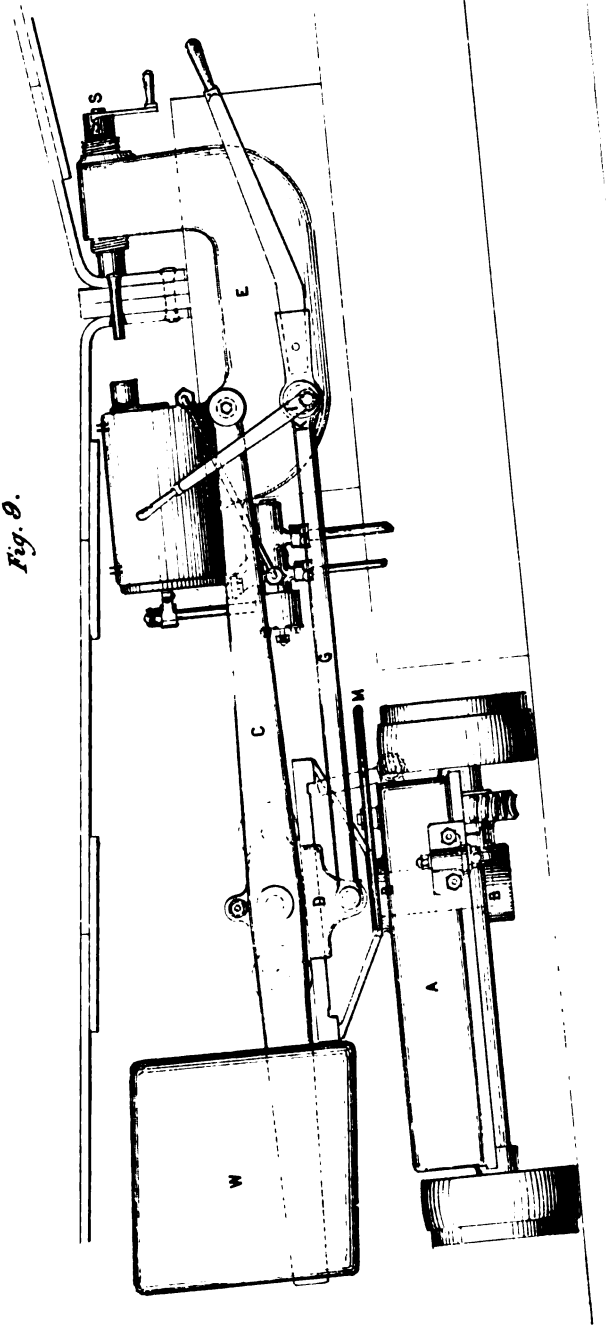

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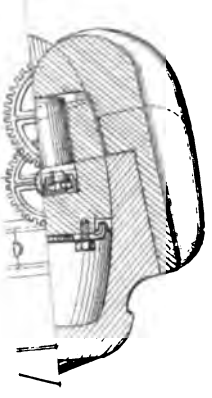

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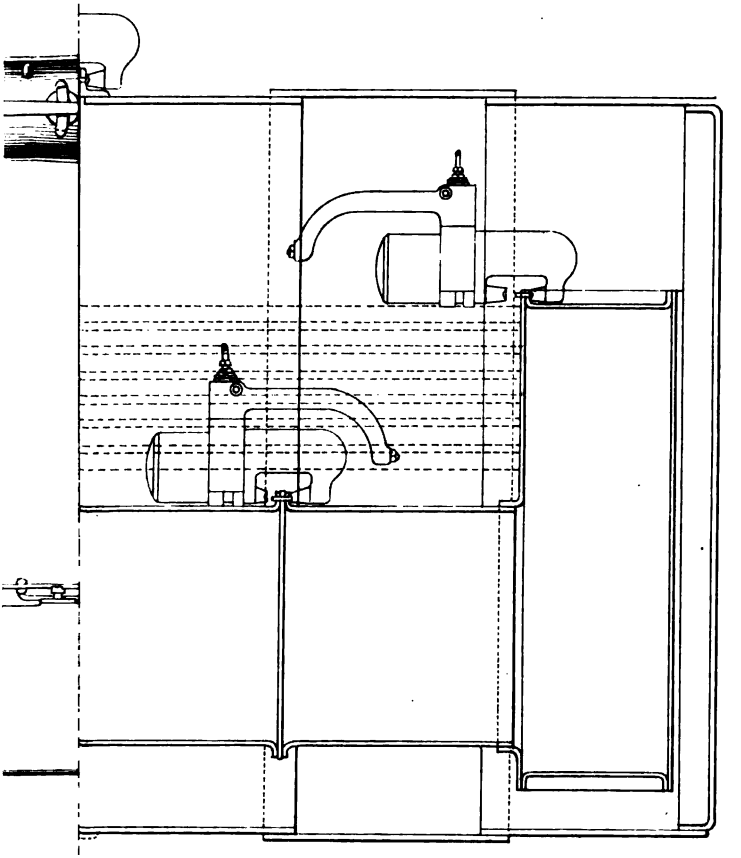

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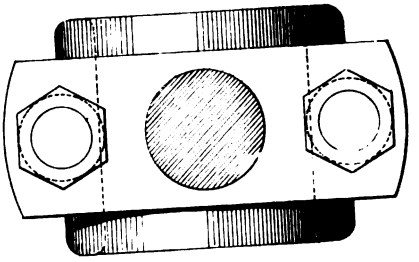

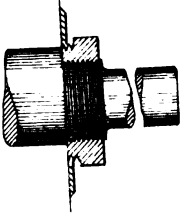

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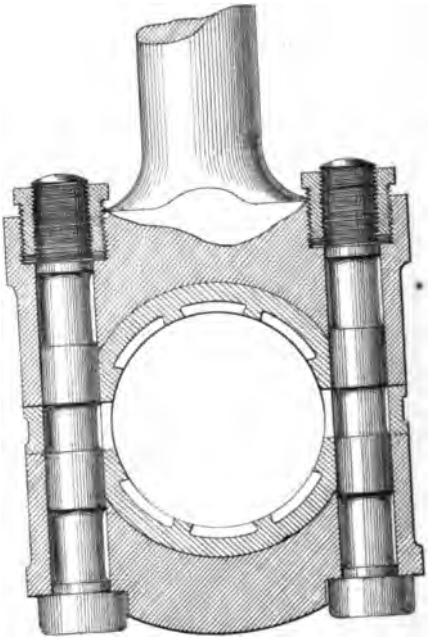

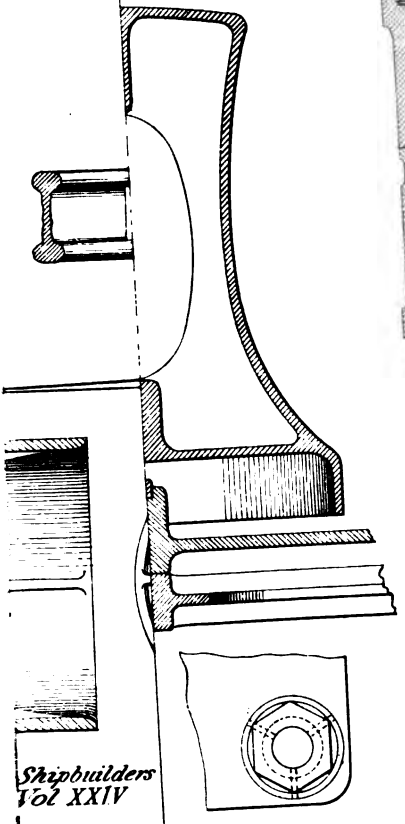

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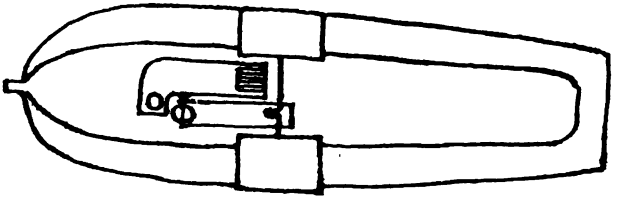

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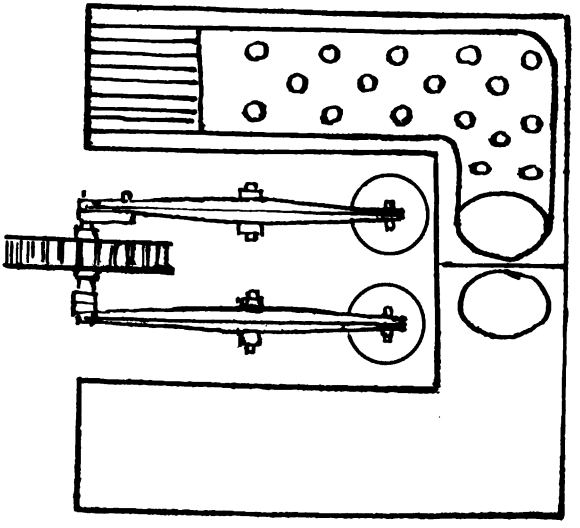

Fig. 8.

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SCALE

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REFERENCE.

- A WROUGHT IRON MUFFLE FOR CONTAINING ARTICLES TO BE TREATED.
- B SIGHTHOLES FOR SEEING WHEN ARTICLES BECOME RED HOT.
- C FLUE FOR ADMITTING AIR TO SECURE MORE PERFECT COMBUSTION.
- D FIREGRATE FOR HEATING THE MUFFLE.
- E FLUE AROUND MUFFLE.
- F SIGHTHOLES INTO FLUE.
- G SERIES OF DAMPERS TO REGULATE THE HEAT.
- H CULVERT LEADING TO CHIMNEY SHAFT.
- J WROUGHT IRON COIL EMBEDDED IN CAST IRON FOR SUPERHEATING THE STEAM.
- K PIPE FOR SUPPLYING STEAM FROM BOILER.
- L PIPE FOR SUPPLYING SUPERHEATED STEAM TO MUFFLE.
- M FIREGRATE FOR HEATING SUPERHEATER.
- N SERPENTINE FLUE.
- P SIGHTHOLE FOR SEEING WHEN SUPERHEATER IS RED HOT.

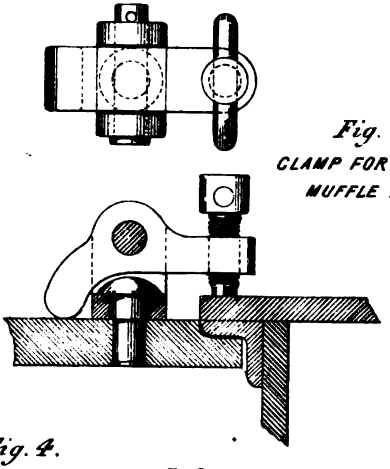
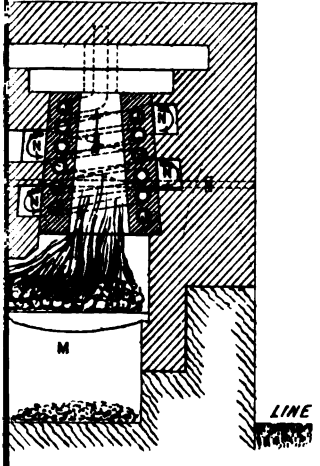


Fig. 6.
CLAMP FOR HOLDING MUFFLE DOOR

Fig. 4.
ELEVATION ALONG LINE 7. 8.



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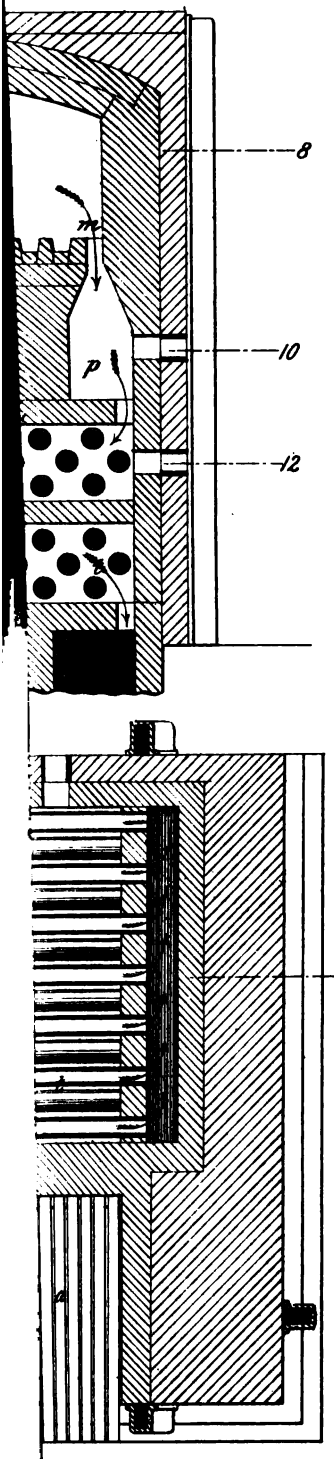
NG LINE 5. 6.



REFERENCE.

- *a.* GAS PRODUCER.
- *b.* COAL FEEDING HOPPER.
- *c.* GAS REGULATING DAMPER.
- *d.* FLUE TO AIR AND MIXING CHAMBERS.
- *h. g.* GAS MIXING CHAMBER.
- *k.* MUFFLE FOR HOLDING ARTICLES TO BE TREATED.
- *l.* GAS INLET TO MUFFLE.
- *m.* GAS OUTLET FROM MUFFLE.
- *t. p'.* REGENERATOR.
- *V.* AIR INLET TO TUBES AND VALVE.
- *S.* FLUE TO CHIMNEY.

THE ARROWS SHEWN THUS (→) INDICATE THE COURSE OF THE HOT PRODUCTS OF COMBUSTION, THOSE SHEWN THUS (→) THE COURSE OF THE AIR THROUGH THE HEATED REGENERATOR TUBES REQUIRED FOR REGULATING THE COMBUSTION.

SCALE

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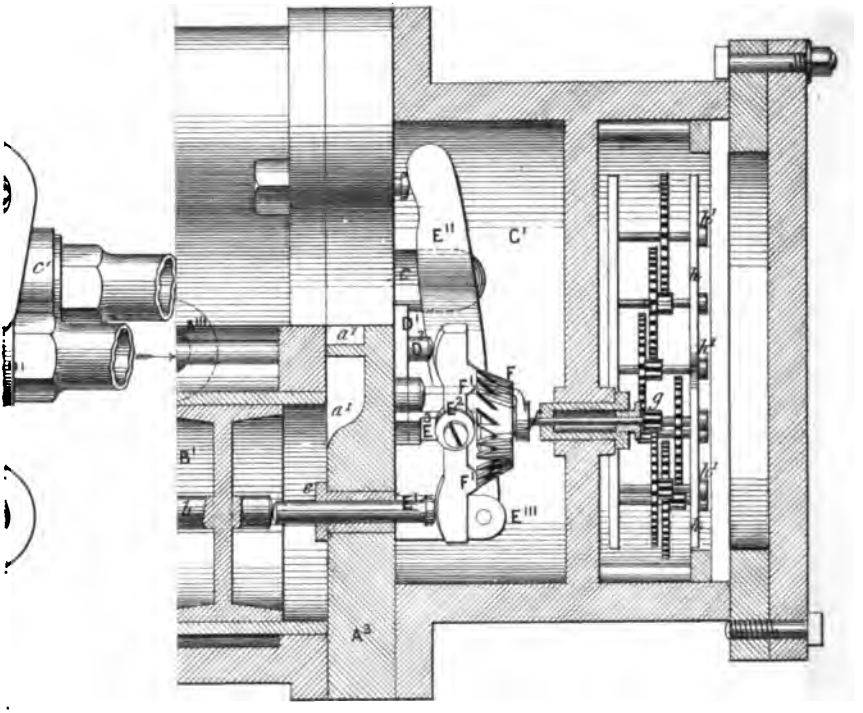

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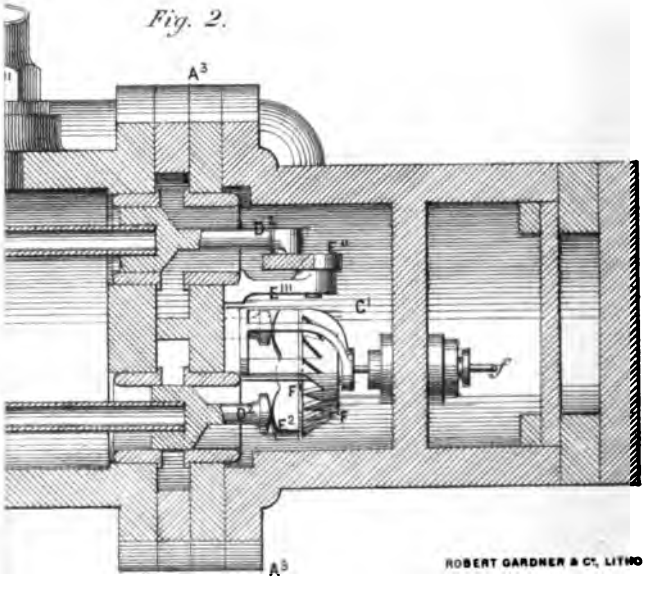

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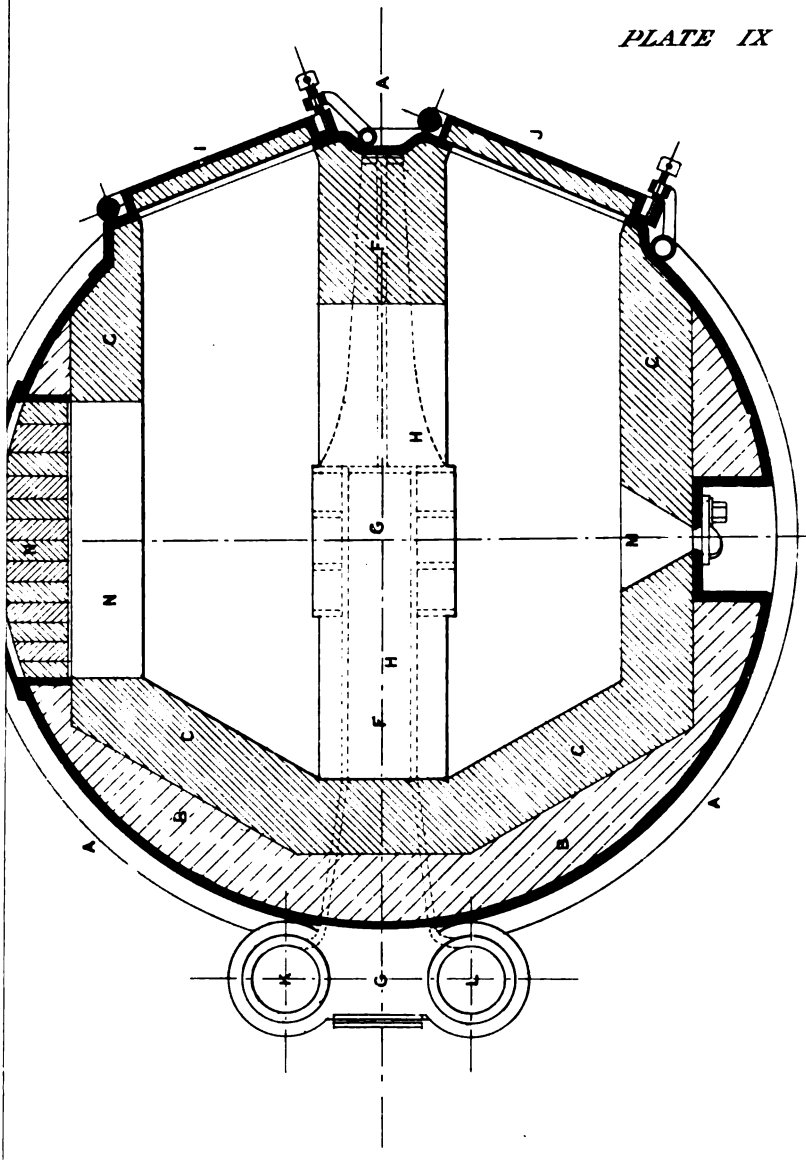

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